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Towards a Carbon Data Science

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Towards a Carbon Data Science

Abstract

This report provides a critical review of the emissions accounting, reporting and footprinting of carbon dioxide (CO_2) currently practiced in the industry to develop a data science for carbon. While providers of carbon footprinting deserve considerable credit for educating asset managers and effectively building an industry, the quality of corporate carbon accounting and reporting still poses significant challenges. Statistical concepts related to carbon footprinting also need further development. We conclude our report by highlighting the three main challenges to be in arriving at Carbon Data Science. First, the vast majority of corporations need to be incentivised to report their carbon emissions accurately, coherently and consistently across reporting schemes. Second, while it seems inevitable for corporations to use estimations in producing their carbon emission inventory, these estimations should be made in compliance with the precautionary principle (i.e. if in doubt, err on the side of the planet). The precautionary principle should equivalently be applied to estimations of carbon emissions by those corporations not (yet) reporting themselves. Third, from an investor perspective concerned about aggregating corporate carbon footprints, the issue of 'double counting' has to be addressed more succinctly. For instance a utility provider's scope 1 is the scope 2 of many other firms and, consequently, some investors' portfolio carbon footprint might be overstated. While we limit our report to CO_2 for simplicity, we consider our findings equivalently applicable to the other greenhouse gases.

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1 Introduction

Climate change is at least until the COP 21 summit in Paris considered the main threat against the future wellbeing of our planet. While modern debates of global warming issues can be traced back to the mid-20th century, it is not until rather recently that the institutional investor community has started to position itself in this debate. Led by a number of organizations such as the Institutional Investors Group on Climate Change (IIGCC), the Investor Network on Climate Risk (INCR), the Investors Group on Climate Change (IGCC), the Montreal Pledge of the United Nations supported Principles for Responsible Investing (PRI), and the Portfolio Decarbonisation Coalition, intense discussions have emerged on how capital can be utilized to mitigate the likely adverse impacts of climate change.

Climate change-related issues shall concern asset owners, with regard to risks and opportunities. With adequate efforts, asset owners will be able to avoid the down-side risks that can bring negative impacts to their asset value. Carbon is a key indicator to better inform asset owners with climate change associated risks and opportunities related to their investments, and enables them to make more sensible investment decisions. To better grasp carbon-related risks and opportunities, one of the key issues is to understand how carbon is measured and presented, as quantified metrics are certainly more comparable and can be applied in different contexts. Hence, this report aims to thoroughly review the current carbon footprinting and reporting landscape, to provide an in-depth discussion about current states and practices, and the remaining challenges left to arrive at a carbon data science.

To achieve this aim, the report first defines carbon footprinting before providing a detailed overview of the commonly used carbon metrics, including a discussion of their trustworthiness. The subsequent section analyses the current state of corporate carbon accounting and reporting as a source of potential data quality concerns. The fourth section discusses the main challenges to get to a carbon data science, namely: corporate carbon reporting quality, the lack of precautionary principle application in estimations of carbon data, and potential double counting of carbon emissions from an investor perspective. The fifth and final section concludes.

2 Common carbon metrics

When we see people speaking of terms such as ‘carbon’ or ‘carbon footprinting’, what are they actually referring to? This section introduces the measurements of carbon that are most commonly used and seen, and further clarifies the definition and use of each metric. To begin

with, a more widely accepted definition of carbon footprinting shall be given as carbon footprinting generally serves as the entry point for most investors in using carbon metrics.

Several academic publications have attempted to give carbon footprinting a clear and universally accepted definition. According to Wiedmann and Minx (2008), "[i]n most cases (literature search in June 2007), 'carbon footprint' is used as a generic synonym for emissions of carbon dioxide or greenhouse gases expressed in CO_2 equivalents." They propose that "the carbon footprint is a measure of the exclusive total amount of carbon dioxide emissions that is directly and indirectly caused by an activity or is accumulated over the life stages of a product." Activities include those of an individual, populations, governments, companies, organisations, processes, industry sectors, etc. Products refer to any goods or services sold to (or purchased by) consumers from the manufacturers or service providers. The authors also suggest that they intentionally include only CO_2 for practical reasons, and refrain from expressing the carbon footprint as an area-based indicator as the total amount of CO_2 is physically measured in mass units, and thus no conversion to an area unit is needed.

Wright *et al.* (2011) defined carbon footprint as a "measure of the total amount of carbon dioxide (CO_2) and methane (CH_4) emissions of a defined population, system or activity, considering all relevant sources, sinks and storage within the spatial and temporal boundary of the population, system or activity of interest".

Chomkhamsri and Pelletier (2011) summarise the common elements amongst the organization footprint guides in their report, which include (i) Accounting principles (ii) Existing methodologies do not use life cycle approach, especially for Scope 1 (iii) Focus on report for management, e.g. reduction (iv) Many build upon old GHG Protocol (v) Most use scope 1, 2, 3 approach. They consider the accounting guidelines for product carbon footprinting are better developed, more prescriptive, and more comprehensive than corporate accounting guides. The focus of corporate accounting guides tends to be on reporting-related issues, whilst substantive technical guidance is lacking.

In Williams *et al.* (2012), the authors suggest that all conceivable emission sources for the subject of interest should be identified and categorized, which essentially covers the area of climate footprinting. In order to do so, a decision-making process must then determine which emission sources are relevant to the subject of the carbon footprint, and which should therefore be included in a carbon footprint calculation. The next step is selecting an appropriate method for translating the measurable activities of each emissions source to a weight of CO_2 and CH_4 emissions. To achieve this, the necessary data should be gathered and the methods applied to

calculate a total weight of CO_2 and CH_4 emissions, taking into account each gas' global warming patenting (GWP), expressed as CO_{2e}. The methods shall be thoroughly documented in order for any future attempt of repeating the carbon footprint can be undertaken with the same methods to ensure the comparability.

The brief review above is intended to inform readers of the basic definition of the term carbon footprint, as a universally accepted definition is the first step towards establishing a suitable measure more accurately representing the subject of interests, in this case, the carbon dioxide emissions produced associated with human-related activities. A well-defined terminology is also helpful to ensure that readers/users of 'carbon footprint' are properly informed of the content that is actually being measured. Furthermore, it ensures that a consensus exists with regard to what carbon footprint refers to when the term is used among different people in different context.

2.1 Carbon footprinting: what metrics are being used and reported?

It is safe to say, whichever carbon metric is used, that the most important thing to consider is: is it (are they) fit for the purposes? In this section, we introduce and summarise the most commonly reported carbon metrics. The metrics can mainly be separated into two types: the absolute carbon emissions and the normalised carbon emission ratios. The most commonly used metrics are summarized in Table 1.

2.1.1 Absolute carbon emissions

- The absolute carbon emission indicates how much emissions in total that are being produced (emitted) by the reporting organisation. Most commonly, it is physically measured and expressed in mass units, such as tonne or metric tonne.

- Purpose and how it is relevant in an investor context – the absolute carbon emissions is a direct measure of the organisation's impact to climate change (caused by the accumulated emissions in the atmosphere). Similarly, in the context of investment portfolio, which contains multiple investees, the absolute emission measure gives an indication of the extent to which a portfolio contributes to global climate change (by funding the accumulated emissions that leads to climate change).

- The main restriction of an absolute measure is the lack of comparability across reporting organisations of substantially different sizes/business models. Since it measures the total amount of emissions produced, it is inevitably driven by the reporting organisation's size, number of products produced, etc. Similarly, for investment carbon footprint analysis, there

is, per definition, a positive relationship between the size of the portfolio and the total amount of emissions.

2.1.2 Normalized carbon emission ratios

- In addition to using absolute emissions data as a performance indicator, it is usually helpful, and indeed more informative, to include other indicators, such as an emission intensity ratio or other normalised ratios, depending on what characteristic is being investigated in relation to the total emission.

- In general, the absolute emissions can be divided by any metric that is appropriate to make the ratio a meaningful performance indicator, for instance, an activity metric (e.g. per unit of production output) or a financial metric (e.g. £ million turnover, investment). As suggested by UK DEFRA (2013), an activity metric is more suitable when aggregating or comparing organisations that share similar characteristics (e.g. the production of similar products) while the financial metric appears more suitable when aggregating or comparing organisations of different characteristics.

- The normalised ratios can usually show the level of 'efficiency' of the reporting organisation in terms of emission performance. They allow comparison over time and across different organisations, sectors, or products without being subject to size, like the absolute emissions.

Table 1. Commonly used carbon metrics

Metric	Data required	Strengths	Weaknesses	Used/mentioned by
Total Emissions / Carbon Footprinting (usually in metric tonnes of CO_2/CO_{2e})	Measured or estimated CO_2 emissions	-Clearly indicate the actual amounts of carbon produced. -Easier to compare with overall emission & reduction target.	-Difficult to put in context with regard to comparability. -Highly correlated to size	-Individual company -Investment analysis (MSCI)
Carbon emissions per million $ invested	Emissions, market value of portfolio	-Better comparability across portfolios of different sizes.	-Subject to changes in portfolio market value.	-Investment analysis (MSCI, Trucost, Kepler Cheuvreux, YourSRI by CSSP)
Carbon emissions per million $ turnover	Emissions, company turnover	-Suitable for aggregating or comparing across more heterogeneous organizations.	-Subject to the nature of business activity.	-Individual company. (UNEP)
Carbon intensity: emissions per unit of output/sales	Emissions, sales/production data of investee/company.	-Allow adjustments of the investee/company sizes. -Indicate the efficiency level and facilitate comparison between companies.	-Subject to data availability and reliability. -Subject to business nature, e.g. pricing strategies. -Not suitable for companies of diversified product profiles	-Individual company (UNEP, UK DEFRA). -Investment analysis (MSCI, Kepler Cheuvreux)
Weighted Average Carbon Intensity (individual carbon intensity x weight in portfolio)		-Indicate portfolio's exposure to carbon-intensive investee. -Less ownership-related calculation noises.	- Does not indicate directly climate change impact	-Investment analysis (MSCI, ET Index)
Emissions versus a reference unit/benchmark		-Indicate the portfolio (company)'s relative performance against a defined target and easy to analyses.	-Benchmark/reference setting can be subjective.	-Investment analysis (2°c Investing)
Emissions normalized mainly by activity metrics (production, fuel sales, volume transported)		-Standardized normalizing factor within industry	-All subject to the nature of business.	-Oil and gas industry (IPIECA)

Please note: based on MSCI (2015), Kepler Cheuvreux (2015), UK DEFRA (2013), the following table provides an overview the most commonly carbon metrics currently used in the industry. Column one reports the respective carbon metric, column two reports the data required to utilize the metric, column three and four report and the strengths and weaknesses of the metric, respectively. Finally, column five reports the source of the metric.

2.2 Key issues to consider: how trust-worthy are these metrics?

Based on current evidence available in Liesen *et al.* (2015), it is not realistic to assume that data quality of reported carbon data (of any kind, absolute or normalised ratios) is of sufficiently reliable level. The authors find that, between 2005 and 2009, less than twenty percent of the hundreds of corporations reporting carbon emissions in their sample reported (i) at least scope 1 and 2, (ii) GHG emissions instead of just carbon emissions and, especially (iii) emissions for more than 90% of all activities of the entire corporations. Even worse, their sample include Europe's large listed companies, of which many have operations falling under the EU ETS and hence should have had the strongest incentives to report accurately. While these results stem from the last decade, there is no subsequent academic evidence that the situation would have enhanced substantially.

However, it is also not realistic either to expect that all the problems can be solved overnight. Therefore, doubts are justified and it seems crucial to understand the methods that are currently being used/followed to compile the data and what technical aspects are the most relevant for data quality. This is done by reviewing and examining the mainstream accounting and reporting standards for carbon/greenhouse gases emissions which organisations follow to compile and report their emission inventory data.

The bottom line should be that the users of these carbon metrics should be made aware of a few things upfront. First, no single metric can show the full picture of the overall carbon profile of a company/portfolio. For investment analysis purpose in particular, alternative metrics (e.g., green/brown sectors) are being developed to complement carbon footprints and to better understand the dispersion of the climate challenges/opportunities within a portfolio. Second, transparency in methodologies applied to produce these metrics is also highly crucial, if not the most crucial, in terms of assessing the reliability as well as comparability across organisations/investments.

3 Current state of carbon emission accounting and reporting

This section outlines the most commonly followed standards and guidelines for carbon accounting and reporting. More specifically, it traces the origin and development of the reported carbon data, raw or processed, which are used for different purposes, such as organizational carbon footprinting (for individual organization) and investment analysis (for asset owners or

managers). It is essential to critically examine the procedure and steps involved in producing the carbon data in order to identify the challenges and to further enhance the quality of the data output.

It should be noted that we focus on carbon footprinting/accounting process at organisational level, as it is, arguably, of higher relevance for investors. Although the product level footprinting does seem more developed in terms of technical details and granularity, we refrain from discussing in too much detail the product footprinting, as this adds another layer of complexity and the direct value-added seems limited from an investment analysis point of view.

3.1 How it is made?

This section introduces the most widely known and followed GHG/carbon accounting standards to date. These standards provide the guidance for any organisation to follow if it wishes to develop its carbon emission inventory and report it to relevant stakeholders.

3.1.1 GHG / Carbon Accounting Guidelines and Standards

a. **The GHG Protocol** is a collaborated work of the World Resources Institute and the World Business Council on Sustainable Development. Since 2004, it has published several sets of standards and guidance with the intention to set the global standard for measuring, managing and reporting greenhouse gas emissions. The most followed standards by organisations/businesses include The Corporate Accounting and Reporting Standard (GHGProtocol, 2004), and Corporate Value Chain Standards (GHGProtocol, 2011a), as well as a separated standard for product life cycle accounting and reporting (GHGProtocol, 2011b). The Corporate Accounting and Reporting Standards provide a set of standards and guidance on each key step of establishing the GHG emission inventory required for reporting or analysis purposes.

b. The 14064 series for greenhouse gases management and related activities published by ISO, the International Organization for Standardization in 2006 is another set of global standard for organisations to follow when developing their GHG inventory. Part 1 of the 16064 (**ISO 16064-1:2006**) series is the most relevant for carbon footprinting at organisational level. It provides specifications with guidance for quantification and reporting of GHG emissions and removals at organisation level (ISO, 2006).

c. The European Commission published a series of document to support the implementation of its regulation on the monitoring and reporting of GHG gases

pursuant to the Emissions Trading Directive 2003/87/EC/. The Monitoring and Reporting Regulation – General guidance for installations (**MRR Guidance document no.1**) explains in detail the main concepts and approaches involved in the necessary monitoring and reporting process in compliance with the trading scheme. It also provides comprehensive guidance on the main technical aspects with regard to the monitoring plan and calculation-based approaches sections, detailing the steps for developing a proper monitoring plan, as well as for applying calculation based approaches, if the trading scheme participants choose to use the calculation based approaches instead of measurement based approaches (European Commission, 2012).

d. The Guidelines for National Greenhouse Gas Inventories published in 2006 by Intergovernmental Panel on Climate Change is intended to update the 1996 *Guidelines* and the associated *good practice guidance* in order to provide internationally agreed methodologies which can be used by nations to estimate and report their greenhouse gas inventories. Although the Guidelines are intended primarily for compiling nation-level GHG inventories, it also works as a manual for any greenhouse gas inventory compiler as it documents the recommended step-by-step process, which can be applied at a wider range of inventory compilations, e.g. at organisation level. Volume 1 (General Guidance and Reporting) and 2 (Energy) of the Guidelines covers the most relevant technical details with regard to developing the inventory, while the other three volumes discuss in more detail the industrial processes and product use, land use and waste associated GHG emissions (IPCC, 2006a, IPCC, 2006b).

A summary of the most commonly used GHG/carbon accounting and reporting standards can be seen in Table 2. It is interesting to notice that none of these guidelines and standards is intended to be prescriptive. As of today, there is little enforcement regarding whether a company should report its emissions in a certain way and how it monitors and calculates its emission inventory, which in our opinion is the main reason that the overall quality of carbon reporting does not live up to expectations. In addition to the lack of enforcement, another major issue concerning the quality of the final carbon footprinting figure stems from the decision-making in each step during the entire process. This since the truncation errors are difficult to avoid, which eventually cause the uncertainties. These uncertainties are inevitably amplified when the data are aggregated. The concern is also mentioned in other studies (e.g. Suh *et al.*, 2004, Lenzen, 2000).

Table 2. The summary of currently existing (and most commonly used) accounting and reporting standards

	Objective	User	Process / Key steps	Checking points
GHG Protocol Corporate Accounting and Reporting Standard	GHG Protocol provides standards and guidance for corporations to prepare and report its GHG emission inventory.	For any organisation that wishes to measure, monitor and report its GHG emissions	Set organisational and operational boundaries. Tracking emissions over time. Identifying and calculating GHG emissions. Managing inventory quality. Accounting for GHG reductions. Reporting GHG emissions. Verification of GHG emissions. Setting GHG targets	The globally-accepted protocol provides standards and guidance for the reporting entity to follow on a voluntary basis.
ISO 14064-1	The international standard (14064-1) provides specification with guidance at organisation level for quantifying and reporting GHG emissions and removals.	For any organisation that wishes to measure, monitor and report its GHG emissions.	Organisational boundaries. Operational boundaries. Quantification of GHG emissions and removals (5 steps). Determine inventory components. Inventory quality management. Reporting	This is an international standard for organisations to follow with discretion, not mandatory regulations. No standardised format for reporting is provided. Suggestions on planning and what to include in the report are given.
UK DEFRA Environmental Reporting Guidelines	This document provides guidelines for companies to report their key environmental impacts. It also introduces the mandatory greenhouse gas emissions reporting guidance.	For companies in complying with the GHG reporting regulation under Climate Change Act 2008, and any organisation reporting voluntarily their environmental matters.	Determine the reporting boundary. Determine the reporting period for data collection. Determine the key environmental impacts. Measuring. Reporting.	Reporting is voluntary for most organisations. Only quoted companies (UK-based) are required to comply with GHG reporting regulation under Climate Change Act 2008. No standard format of report is provided, only suggestions of what to report are made. Transparency is one of the key principles for reporting. No prescribed methodology for quantification or reporting, only recommendations are provided. No requirement for the emission data to be independently verified or assured.

EU ETS Monitoring and Reporting Regulation and Guidance	The regulation outlines and defines all the subjects that matter for complying with the EU's emissions trading directive with regard to monitoring and reporting. The guidance document provides details for the regulated installations for follow to prepare their monitoring and reporting under the trading scheme.	Any installation that is subject to the emission trading directive, or for those who opt-in the scheme on a voluntary basis.	Start of monitoring period. Allowance allocation **Monitoring plan: data collection, sampling of materials and fuels, laboratory analyses of fuels and materials, maintenance and calibration of meter, description of calculations and formulae to be used, control activities, data archiving, regular identification of improvement possibilities End of monitoring period Verification and report Report submission	While regulations for emissions trading and its monitoring/reporting are in place, the guidance is not legally binding but rather represents the views of European Commission. Annual emissions report submitted to the central authority require verification. Six electronic templates are provided by the Commission:
IPCC Guidelines for National GHG Inventories	The guidelines were produced to provide internationally agreed methodologies intended for use to estimate and prepare GHG inventories to report to the UNFCCC. The guidelines update the 1996 guidelines and associated Good Practice Guideline.	For countries as well as inventory compilers who wish to or are required to estimate and prepare their GHG inventories for reporting purposes.	Data collection including gathering existing data, generating new data and adapting data for inventory use. Uncertainty identification and assessment. Key category analysis. Time series consistency. Quality assurance and control. Precursors and indirect emissions. Reporting.	Provide standardised reporting tables covering all relevant gases, categories and years. Also required is a written report documenting the methodologies and data used to prepare the estimate. The guidelines are primarily for the national-level GHG inventories, however, most methodologies can be adopted at more disaggregate level, e.g. companies, installations.

Please note: the following table reports the most commonly used reporting standards for greenhouse gas emissions. Column one reports the name of the respective guidelines, column two the objective, column three the primary user, column four the key steps and column five reports the checking points. The information displayed in the table is based on the following sources: GHG Protocol (WRI and WBCSD, 2004), ISO (2006), European Commission (2012), IPCC (2006)

3.1.2 The standard procedure at a glance

Developing the emission inventory usually involves several steps. In European Commission's (2012) guidelines for monitoring and reporting emissions, it suggests that all monitoring activities involved in the entire process shall be documented into written procedures, which allow any future attempt of the same procedure can be carried out in a consistent manner. Having a basic knowledge of these steps helps us understand most importantly, how carbon footprint is achieved, what elements are involved, and what factors could cause uncertainties, which essentially affect the reliability of carbon data. In other words, the entire procedure can be separated into two parts: the boundary setting part and the quantification part.

3.1.2.1 Setting reporting boundary

To begin with, a boundary of any organization that intends to develop its emission inventory needs to be determined: how much should be included? The boundary setting process can only be completed after a number of decisions are made. First, the organisational boundary should be determined, which usually requires the decision making between two approaches: control or equity share approach. The next step is to determine the operational boundary, which covers the subjects of types and sources of emissions. Emissions (for current reporting purposes) are classified into two types:

- Direct emissions, which are physically produced by combusting fuels, production process, or other activities from the facilities owned or controlled by the organisation/business which intends to conduct a footprinting.
- Indirect emissions: the actual emissions are produced by facilities not owned/controlled by the reporting entity but the emissions are produced as the consequences of certain activities by reporting entity. Under the GHG Protocol, indirect emissions are further classified into two types (i.e. scopes): energy use-related indirect emissions and all other upstream and downstream indirect emissions not covered in energy use-related indirect emissions. See the summary in Table 3 below.

Table 3. Summary of emission types

Direct	Scope 1	Direct GHG emissions come from sources that are owned or controlled by the reporting entity. More specifically, emissions are physically produced on site from activities such as combustion of fuels (both stationary and mobile), production processes, and/or fugitive emissions.
Indirect	Scope 2	Electricity indirect emissions for the reporting entity come from the emissions of consumed electricity/energy/steam. The emissions are produced as the consequence of reporting entity's activities (electricity consumption), and are physically produced by electricity generation sites. Essentially the electricity indirect emissions are direct (scope 1) emissions of the electricity generation plants/companies. Transmission and distribution (T&D) loss is a special category of scope 2 emissions as part of the electricity (and the associated emissions) is consumed (lost) during T&D. This should usually be reported by the company who owns or controls the T&D operation, not end consumers, which avoids double counting within scope 2.
	Scope 3	Other indirect emissions to be reported cover all emissions that occur in any step/part involved in the full value chain of the reporting entity, including upstream (extraction/production of purchased materials and fuels, transportation, energy and electricity, business travel and commuting, leased assets) and downstream (transport and distribution, processing and use of sold goods, end-of-life treatment of sold goods, leased assets, franchises and investment) activity-related emissions. Note: Scope 3 emissions are physically produced on sites/facilities not owned or controlled by the reporting entity. Essentially Scope 3 are other entities' scope 1 emissions.

Please note: the following table outlines the different scopes of greenhouse gas emissions. The reported information is based on the following sources: GHG Protocol Corporate Accounting and Reporting Standard (2004), GHG Protocol Corporate Value Chain Accounting and Reporting Standard (2011), CDSB Climate Change Reporting Framework (2012).

3.1.2.2 Quantification process (monitoring, measuring and calculating)

After all boundary setting-related decisions are made, it should be ready to proceed to the next step: the quantification process, which involve more decision making on technical aspects. The process can be roughly separated into three steps:

- First, a quantification method should be decided. There are several feasible and commonly applied approaches to quantify carbon emission, including direct measurement approach, mass balance, calculation-based and a combination of different approaches.

- Once the business decides which method should be applied, the data required to compute the final carbon emissions figure need to be collected. For the direct measurement approach, the meter reading from the measurement or monitoring device should be recorded. As for calculation-based approach, activity data from all sources of emission identified in the boundary setting process and the suitable emission factors need to be collected in order to use these data to calculate the final carbon emission figures.
- Once all required data are collected, the last step is to apply the quantification calculation method chosen, which is primarily to use the correct data in the correct formula.

3.2 How it is presented?

After carbon data have been properly collated, they can be utilized for different purposes, such as being used internally for strategic or emission efficiency performance analysis or used externally to communicate with relevant stakeholders regarding it emission performance. The organisation also has the options to either reports via its own platform, for instance by its annual report or a separated environmental performance report (usually integrated into the sustainability/CSR report) or chooses to report under other reporting platform or schemes.

Kauffmann *et al*. (2012) provides a comprehensive review on the current corporate GHG emission reporting activities with a focus on government schemes. The reporting serves different purposes for different groups. For investors, the reported information (of carbon/GHG emissions) can act as levers for corporate climate change action by inspecting the emission information and potentially integrating it into investment decision-making, though there is little evidence currently showing the actual weight of emission information as an integral part of investment decision.

Currently a certain proportion of businesses in Europe are required to report their emissions under specific regulation, while others can choose to report voluntarily, and still others do not report at all. European Union's Emissions Trading Scheme is one of the large-scale mandatory reporting frameworks, which requires all installations covered by the scheme report annual their verified emissions to EU central authority (EuropeanCommission, 2003). Quoted companies in the UK are now also required to report their emissions as well as other environmental performance indicators under Climate Change Act 2008 and The Companies Act 2006 (Strategic Report and Directors' Report) Regulation 2013.

Another major channel for businesses/organisations to publish and report their carbon emissions performance is the voluntary reporting initiatives. The most widely known ones

include the Carbon Disclosure Project (CDP), which is one of the first initiatives that promote and specialise in corporate environmental information disclosure and sharing of climate change-associated risk. Some businesses may choose to report their emissions in its own report and they may choose to follow certain guidelines in terms of what and how to report. For instance, Global Reporting Initiative (GRI) is a reporting framework for corporations who wish to report and disclose their sustainability performance.

4 Current challenges of carbon footprinting

This section discusses the most relevant problems and challenges facing carbon reporting, primarily from an investor perspective. The purpose is to identify the key aspects that matter the most for any party, including asset owners and institutional investors, who are keen to incorporate carbon emission-related information into their investment activities or other agents interested in using such information. Identifying the problems is the first step to make further enhancement on the overall quality of the carbon emission data. A summary of the relevant challenges and problems is provided in the Table 4, which is then followed by a more in-depth discussion on the further issues that matter and a concluding remark. The summary table is structured in the way that reflects the topics discussed in the previous two sections and arranged in the order of information flow from the origin (accounting standards) to the end product (carbon metrics).

4.1 Corporate carbon reporting quality

The quality of reported carbon data deserves substantial attention due to the issues inherent from the procedures examined in section 3.1 and summarised in Table 4. However, data of low quality are essentially of little or no value for purposes such as carbon footprinting for investment analysis or internal assessment. In Kauffmann *et al*. (2012), a PwC and CDP 2010 survey reveals that the main reason for a very low level of reporting activity results from the lack of adequate infrastructure to gather data across different parts of business operations. It appears at this moment costs for setting up the measurement system, staff with expertise as well as the maintenance of accounting and reporting system form a first barrier for businesses who intend to develop and report their emission inventory.

In addition to the challenge of lacking reporting activities, the reported carbon data are also facing the challenge with regard to their quality and reliability. Most reports suffer from incompleteness of coverage (Liesen *et al*. 2015), which is likely caused by the discretions allowed during the boundary setting process as well as costs-related issues. Moreover, any discretion

allowed in each step during the quantification process, including methodological choices, data collection, estimation factors, result in added-up uncertainties regarding the quality of final carbon emission figure. Last, but not least, insufficient level of assurance and independent verification on the reported data lead to a low level of creditability of the data.

Table 4. Crucial issues facing the status quo of carbon accounting, reporting and footprinting

Process Step	Crucial issues	Causes	Relevance	Ways to improve
Accounting and reporting standards	The degree of applicability and compliance.	No sufficient enforcement or incentives	Standards/policy makers; users who adopt the standards, such as organisations who either are required to report or report voluntarily.	Different standards and frameworks can consider reducing the inconsistencies and improving the coherence and compatibility, in particular regarding technical aspects.
Carbon emissions raw data There are many steps involved in producing emission data to be used for reporting, and each step can add problems and uncertainties to the quality of data.	The uncertainties and discretions involved.	Boundary setting: Organisational boundary Operational boundary	Organisations, data compilers, data users (e.g. asset managers for investment analysis)	
	The uncertainties and discretions involved as well as requirements for high degrees of efforts and expertise.	Quantification process: Methodological choices Data collection Calculation		
	Data quality	The level of assurance and independent verification is low as in most cases it is not compulsory to have emission data verified.		
Carbon metrics (processed data) The metrics used/published by organisations have its own issues in addition to the issues related to emission data. As asset managers use these metrics to conduct analyses on their investment, the issues are inevitably inherent.	Communications lack transparency i). What are reported and what they mean? ii). What methodologies are used to come to the metrics reported? iii). A single metric cannot show a full picture	No enforcement and a lack of consensus with regard to what and how much to report in place except for limited regulatory schemes, such as EU ETS.	Asset owners / institutional investors and any user of carbon metrics.	Be transparent on every aspect involved in the reporting process.
	Difficulties in comparison across companies: i). What is the coverage of the report? In most cases the reports are incomplete in terms of corporate reporting (Liesen et al. 2015). ii). What really matters?	A lack of consensus and enforcement with regard to what and how much to report. A part of the problems are also inherited from raw data collation.		Be transparent upfront with regard to the reporting scope. Precautionary principles should be adopted to assume the worst case scenario when the complete scope of reporting is not achieved.

	Compounded uncertainties and inaccuracies after aggregation	As emission data from each individual organisation / company carry a certain degree of uncertainty and accuracy, it is inevitable that the uncertainty is amplified when the company level data are aggregate into portfolio level.		Be more transparent about the uncertainties involved. Include uncertainty assessments for all, especially quantitative analyses (for raw data as well).
Carbon footprinting	Failure to apply the Precautionary Principle	For some reason, none of the established processors of carbon appears to have yet the idea to introduce the precautionary principle for its estimations	There is a strong incentive for corporations and other commercial organizations to make themselves good. As the planet does not always have a vocal advocate at the table, not applying the precautionary principle, probably means that, if in doubt the commercial organization favours its own side instead of the planet's side	It would be simple to apply the precautionary principle
	Failure to sufficiently control for double counting of aggregate carbon emissions	Corporations are aiming to least report scope 1 and 2 and ideally even 3. While this is very laudable and very useful for corporations, it faces investors holding multiple corporations with the challenge that one companies scope 1 may be another companies scope 2 and 3	Investors might lose trust in portfolio carbon footprint if the double counting issue cannot be addressed	If corporations were to report their scope 2 and 3 per organization that supplies them, investors could adjust their carbon footprint according to their portfolio holdings

Please note: the following table provides a summary of the critical issues of carbon accounting and reporting.

4.2 Precautionary Principle?

To reduce the uncertainty in commercial actors interpreting their discretion, (O'Riordan, 1994) popularised the precautionary principle with their seminal book over two decades ago. The precautionary principle was originally developed for states at the macro level, it is, however, equally applicable for carbon footprinting at the micro level. At the macro level, Principle 15 of Annex 1 of the United Nations Rio Declaration of 1992 (UN, 1992) defined the precautionary principle as follows:

> "In order to protect the environment, the precautionary approach shall be widely applied by States according to their capabilities. Where there are threats of serious or irreversible damage, lack of full scientific certainty shall not be used as a reason for postponing cost-effective measures to prevent environmental degradation."

Taken from the macro state level to the micro level of carbon footprinting, the precautionary principle simply states that whenever those that conduct a carbon footprint exercise discretion, this discretion shall be employed in a manner that is least harmful for the planet. In order words:

> If in doubt, err on the side on the planet.

Given the numerous inconsistencies in conceptual carbon accounting, corporate carbon reporting and carbon footprinting (Townsend and Barrett, 2013), there should be a considerable number of situations in which those 'making' the carbon numbers could apply the precautionary principle. Surprisingly, however, we are unaware of the application of the precautionary principle in carbon footprinting so far.

4.3 Double counting from an investor perspective?

Double counting of carbon emissions is a challenge known in the supply chain context for quite a while (Caro *et al.*, 2013, Lenzen, 2008). It stems from the very laudable ambition of individual corporations to display their scope 1, 2 and 3 emissions, whereby their scope 2 and 3 emissions, however, occur outside their own organisation. While this is an excellent idea when analysing a single organization, it becomes a substantial challenge for anyone aiming to analyse an aggregation of organizations, either in the supply chain or in terms of an investment portfolio.

The size of the problem becomes prevalent when one considers Raynauld's (2015: 21) view that "double counting can reach about 30-40% of an institutional investor's portfolio emissions."[1] While some providers of carbon footprints adjust for double counting, not all do or at least communicate their consideration of double counting. At a recent event in Zurich hosted by Sustainable Finance Switzerland, in November 2015, four leading providers of carbon footprints were requested to assess the same example portfolio. While South Pole displayed an adjustment for double counting, Inrate disclosed numbers including double counting, while MSCI ESG and Trucost did not mention the issue at all.[2]

Neither Raynauld's (2015) recent and very detailed carbon compass nor academic work on double counting (ie. Caro, *et al*. 2013; Lenzen, 2008) consider this challenge to be fully resolved and to our best understanding, South Pole is also not claiming to have found the ultimate solution. If corporations were to disclose their scope 2 and scope 3 emissions by exact source, analysts could understand from which other organization these emissions stem and investors would have the opportunity to precisely adjust for double counting. As companies are, however, unlikely too excited about disclosing and frequently updating their precise supplier base, new thinking might be needed that goes beyond the scope 1, 2 and 3 paradigm.

5 Concluding outlook on a carbon data science

This report provided a critical review of the emissions accounting, reporting and footprinting of carbon dioxide (CO_2) currently practiced in the industry to develop a data science for carbon. While providers of carbon footprinting deserve considerable credit for educating asset managers and effectively building an industry, the quality of corporate carbon accounting and reporting still poses significant challenges. Statistical concepts related to carbon footprinting also need further development.

We conclude our report by highlighting the three main challenges to be in arriving at Carbon Data Science. First, the vast majority of corporations need to be incentivised to report their carbon emissions accurately, coherently and consistently across reporting schemes. Second, while it seems inevitable for corporations to use estimations in producing their carbon emission inventory, these estimations should be made in compliance with the precautionary principle (i.e. if in doubt, err on the side of the planet). The precautionary principle should equivalently be

[1] For a detailed overview on the double counting problem, we recommend Chart 7 in Raynaud, J (2015). Investor guide to carbon footprinting, *Carbon Compass,* Kepler Cheuvreux www.iigcc.org/files/publication-files/Carbon_Compass_final.pdf

[2] The full slide deck of this event is available here www.sustainablefinance.ch/upload/cms/user/IIGCC_SSF_Carbon_Foot_print_workshop_WEB.pdf

applied to estimations of carbon emissions by those corporations not (yet) reporting themselves. Third, from an investor perspective concerned about aggregating corporate carbon footprints, the issue of 'double counting' has to be addressed more succinctly. For instance a utility provider's scope 1 is the scope 2 of many other firms and, consequently, some investors' portfolio carbon footprint might be overstated. While we limit our report to CO_2 for simplicity, we consider our findings equivalently applicable to the other greenhouse gases.

Looking forward, perhaps the way carbon emissions are counted (at the moment) is overly complicated from mitigating climate change point of view. While the concept of indirect (i.e. scope 2 & 3) emissions has its value for informing each organisation of the risks and opportunities related to emission management, at the end of the day, only the direct (i.e. scope 1) emissions, which are actually physically produced and emitted to the atmosphere, increase the risks the rising temperature and global climate change. Hence, the basic definition of scopes might have to be discussed going forward to engage corporations and investors alike.

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