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Principles for accurate GHG inventories and options for market-based accounting

Matthew Brander[1] · **Anders Bjørn**[2,3]

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Abstract

Purpose Market-based GHG accounting allows companies to report their emissions based on the purchase of emission attributes. This practice is widespread for reporting 'scope 2' electricity emissions and has recently been proposed for both 'scope 1' (direct) and 'scope 3' (other value chain) emission sources. However, the market-based method has been criticised for undermining the accuracy of GHG disclosures, and it is therefore highly important to explore the requirements for accurate GHG inventories and the solutions to market-based accounting.

Methods This paper uses two methods: firstly, thought experiments are used to identify principles for accurate corporate GHG inventories and, secondly, formal prescriptions are developed for possible solutions to market-based accounting.

Results and discussion The findings identify six principles for accurate corporate GHG inventories, which are then used to inform the development of two possible solutions. The first solution is to report changes in emissions caused by company actions separately from the GHG inventory, including any changes caused by the purchase of emission attribute certificates. The second solution proposes a causality requirement for the use of emission attributes in GHG inventories. Although the analysis focuses on corporate or organisational GHG inventories, the principles and solutions apply equally to attributional product carbon footprinting and life cycle assessment more broadly.

Conclusions We emphasise that inventories are only one form of accounting method, and their accuracy should not be undermined by attempting to fulfil functions that are best served by other methods.

Keywords Corporate GHG inventory · Scope 2 · Market-based accounting · Carbon accounting · Accuracy · GHG protocol · Product carbon footprint · ISO 14067

1 Introduction

An increasing number of companies and other types of organisations are calculating and reporting their greenhouse gas (GHG) emissions, for purposes including target setting and internal abatement planning, disclosure to investors and other stakeholders, and compliance with mandatory reporting regulations (M. LoPucki 2022). GHG accounting methods and practices are continually evolving as reporting entities and standard setters attempt to meet a range of objectives, such as improving accuracy, increasing participation in disclosure programmes, incentivising and reporting on GHG reductions, and achieving reduction targets at least cost (GHG Protocol 2022a). One evolving area of GHG accounting practice is the use of 'market-based accounting', which broadly involves contractual arrangements for 'emission attributes', whereby the reporting entity buys the right to use a specific emissions rate to calculate its GHG inventory (GHG Protocol 2022b).

A prominent example of market-based accounting is the use of energy attribute certificates (EACs) for 'scope 2' emissions (the point-of-generation emissions associated with purchased electricity, steam, heating, or cooling) (WRI 2015). The use of market-based accounting is also proposed

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✉ Matthew Brander
Matthew.Brander@ed.ac.uk

[1] University of Edinburgh Business School, Edinburgh, UK

[2] Centre for Absolute Sustainability, Technical University of Denmark, Kongens Lyngby, Denmark

[3] Section for Quantitative Sustainability Assessment, Department of Environmental and Resource Engineering, Technical University of Denmark, Kongens Lyngby, Denmark

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for 'scope 1' emissions (emissions from owned or controlled sources), e.g. renewable natural gas certificates (Green Gas Certification Scheme 2022), and 'scope 3' (other value chain emissions), e.g. green steel certificates (ArcleorMittal 2022) and sustainable aviation fuel (Envizi 2021). The GHG Protocol, one of the leading international standard setters for GHG accounting, is currently consulting on the future of market-based accounting (GHG Protocol 2022b).

However, there are concerns that the purchase of emission attribute certificates does not reduce emissions (Gillenwater 2013; Gillenwater et al. 2014; Hamburger and Harangozó 2018; Hamburger 2019) and that the use of market-based accounting undermines the accuracy of GHG inventories (Brander et al. 2018b; Monyei and Jenkins 2018). Moreover, market-based accounting allows companies to report that they have fulfilled reduction targets without reducing emissions (Bjørn et al. 2022). Given the widespread use of market-based accounting for scope 2 (Heeter et al. 2022) and the current review of the GHG Protocol guidance (WBCSD/WRI 2022a), it is important to explore whether market-based accounting can be redesigned in a way that addresses these concerns, or whether alternative accounting methods should be used instead.

Although there are existing studies that highlight the impact of market-based accounting on the accuracy of GHG inventories (Brander et al. 2018b; Monyei and Jenkins 2018), these studies do not provide an in-depth analysis of the necessary requirements for an accurate value chain inventory. Other recent literature on scope 2 accounting provides a detailed discussion on specific technical issues. For example, Robinson and Sullivan (2022) explore the spatial boundaries of electricity markets in the USA, and Tranberg et al. (2019) illustrate the importance of including cross-border flows of power in grid emission factors. On a different technical issue, Holzapfel et al. (2023) discuss solutions for avoiding the double counting of emissions caused by market-based accounting within life cycle assessment (LCA) and corporate GHG inventories. However, these studies do not discuss the underlying or implicit principles for what constitutes an accurate inventory, nor whether addressing specific issues such as double counting is sufficient for ensuring accuracy.

Another recent study proposes a new approach for reporting scope 2 emissions, based on reporting marginal emissions for consumption and marginal avoided emissions from generation (He et al. 2021). However, the focus of their proposal is on quantifying the change in emissions caused by company actions rather than creating an accurate inventory of the emissions from processes used in a company's value chain. The present paper therefore contributes to the existing literature by providing an explicit exploration of the principles for accurate value chain inventories and by proposing possible solutions for market-based accounting with the aim of ensuring accuracy. A further contribution is the paper's exploration of causality and its potential role in accurate inventory reporting.

The current paper is largely focused on market-based accounting within corporate-level GHG inventories, as this is where much of the current debate on the use of market-based accounting is taking place. This is especially the case due to the GHG Protocol's current review of the existing market-based accounting rules for scope 2 corporate reporting (GHG Protocol 2022a) and possible extension to scopes 1 and 3 (GHG Protocol 2022b). However, the issue of market-based accounting is equally important and applicable to other forms of environmental accounting methods, e.g. ISO 14067 for carbon footprinting products (ISO 2018a), and also within product environmental footprinting (PEF) or LCA more broadly (European Commission 2012). A number of recent initiatives for product-level accounting discuss or endorse market-based accounting (Catena-X 2022; Together for Sustainability 2022; WBCSD 2023) and often point to corporate-level standards as the source for market-based guidance. Hence, while this paper focuses on market-based accounting at the corporate level, the conclusions apply equally to product-level accounting as well.

The paper is structured as follows: Section 2 describes the research methods used, Section 3.1 analyses existing norms or principles for accurate GHG inventories, Section 3.2 sets out two possible options for market-based accounting, Section 4 discusses the strengths and weaknesses with the proposed solutions and a number of other related issues, and Section 5 offers concluding remarks.

2 Methods

This paper uses two methods. The first is the use of thought experiments to identify existing norms or principles for what is regarded as an accurate corporate GHG inventory; that is, the thought experiments are used to derive principles that value chain inventories should follow in order to reflect what end users expect them to reflect. Thought experiments are a widely used research method in a number of academic disciplines including the natural sciences, philosophy, and political science (Frappier et al. 2012; Kornberger and Mantere 2020) and broadly involve asking 'what if' questions. The form of thought experiment used in this paper is to describe specific scenarios in which GHG emission and removal claims are made and whether those claims would be considered accurate by end users, in order to identify the implicit principles for what constitutes an accurate value chain inventory. This form of thought experiment is intended 'to make available in a theoretical way those tacit practical commitments' (Gendler 2010, p. 40) that are implicit or embedded in common practice.

Thought experiments are rarely named as a research method within the field of environmental accounting, although there are instances of studies where they are explicitly identified as the research method. For example, van den Bergh et al. (2015) describe the method they use to develop guidelines for studying environmental problem shifting as a 'thought experiment'. However, thought experiments appear to be used reasonably often in the environmental accounting literature but tend to be described as 'hypothetical' or 'worked' examples. One example within the field of LCA is Ekvall et al.'s (2005) thought experiment using the Thorskog Castle conference centre to explore the implications of using attributional or consequential LCA.

Although the accounting rules for compiling GHG inventories are determined by convention (Bebbington and Larrinaga 2022), this does not entail that the accounting rules can take any form that is stipulated through a standard-setting process, as any rule will ultimately be judged against broader norms or principles for what constitutes an accurate inventory. For example, the Renewable Energy Directive stipulates that member states can report the electricity used to charge electric vehicles (EVs) as four times its own energy content in order to support the policy objective of incentivising EVs (European Commission 2018, p. 127). If this were intended as an inventory of energy flows within the life cycle of EVs, it would not be considered accurate. The purpose of the thought experiments is to identify the underpinning principles for what constitutes an accurate value chain inventory.

The thought experiments focus on what is required for accurate inventories of whole value chain emissions, in the sense of whether such inventories reflect the emissions from sources used in the full life cycle of the reporting entity's products or services. We use the term 'value chain' to refer to 'the full life cycle of a product or process, including material sourcing, production, consumption and disposal/recycling processes.' (WBCSD 2011), including the processes directly owned or controlled by the reporting company itself, i.e. effectively encompassing scopes 1, 2, and 3. This clarification is important as in some contexts, 'value chain' has been used to refer only to scope 3 (WBCSD/WRI 2011a), whereas more general definitions of 'value chain' encompass the whole life cycle. It is important to highlight that the thought experiments focus on the requirements for accurate value chain inventories, rather than the requirements for accurate consequential assessments, which aim to quantify the system-wide change in emissions caused by an action or intervention (Brander 2022a).

It is also worth noting that the thought experiments focus on 'accuracy' in the sense of whether the GHG accounts reflect what end users expect them to reflect. It is necessary to make this clarification as common definitions of 'accuracy' within environmental accounting standards tend to offer a narrower conception of this term, focusing only on minimising the under- or over-estimation of emissions (WBCSD/WRI 2004; European Commission 2012; WRI 2015; ISO 2018b), rather than on whether the GHG accounts reflect what they are intended or expected to reflect. If end users expect the inventory to show the emissions from the processes physically used in the company's value chain, then in order to be accurate, the inventory must show those emissions. Accuracy in this broader sense appears to be essential to the application cases for value chain inventories; for example, if the accounts are used to hold the reporting entity accountable for its value chain emissions, then it is essential that the accounts do accurately reflect those emissions. Accuracy is distinct but is related to other principles for environmental accounting; for example, accuracy is likely to be a necessary precondition for relevance, i.e. serving decision-making needs (WBCSD/WRI 2004), but is not sufficient for relevance, as information may be accurate but not useful for decision-making.

The thought experiments use scenarios involving combinations of the following features: traceability to the specific source physically used in the value chain, traceability to an activity pool[1] but not to the specific source physically used in the value chain, the use of market-based attributes from sources within or outside the activity pool, and the presence/absence of a causal relationship between the reporting entity and a specific source. These features were selected either because they appear to be standard practice in value chain accounting, e.g. in the case of identifying the specific source physically used (WBCSD/WRI 2004, 2011a; ISO 2018a), or because they appear within discussions on the requirements for the market-based accounting. For example, the current *scope 2 guidance* states that 'contractual instruments should be sourced from regions reasonably linked to the reporting entity's electricity consumption' (WRI 2015, p. 65), and studies within the academic literature also highlight this feature (Hufen 2017; Robinson and Sullivan 2022). This indicates that the physical proximity or connection between the activity from which attributes are sourced and the reporting entity is relevant to the accuracy of the value chain inventory. In the case of 'causal relationships' (sometimes referred to as "additionality"), the lack of this feature has been suggested as one reason for the inaccuracy of market-based claims (Brander et al. 2018a; Bjørn et al. 2022), although the current scope 2 guidance itself explicitly argues that causality is not necessary for market-based

[1] The term 'activity pool' is introduced here to refer to the set of emission sources which may physically serve the reporting entity, within which further traceability to the specific physical sources used by the reporting entity is not possible. An activity pool might be an upstream supply pool such as the generation technologies supplying a public electricity grid or a downstream set of sources such as waste disposal facilities for the products sold by the reporting entity.

accounting. This indicates that it is important to explore the relevance of causal relationships to the accuracy of value chain inventories.

The second method used in this paper can be described as 'normative method development', i.e. the proposal of prescriptive rules for how corporate GHG inventories should be undertaken (Brander 2022b). The proposed rules are based on the identified implicit principles for accurate corporate GHG value chain inventories and also further considerations, such as consistency with the fundamental characteristics of attributional inventories (Brander 2022a). The rationale and explanation for the proposed rules are provided following the formal specification of the rules themselves. The rules are formulated using the terminology employed in GHG Protocol and ISO standards in order to convey how these solutions would look within a GHG accounting standard. 'Shall' indicates a requirement, 'should' indicates a recommendation, 'may' indicates a permission, and 'can' indicates a possibility or capability (ISO 2022).

3 Results

The analysis is divided into two parts. Section 3.1 explores existing implicit principles or conditions for accurate value chain inventories. Section 3.2 sets out two possible solutions to the use of market-based accounting.

3.1 Principles for accurate GHG inventories

There appears to be a well-established principle that if an emission source is physically used within a company's value chain, then the company should report the emissions from that specific source in its value chain inventory (Ekvall and Andræ 2006; WBCSD/WRI 2011b). For example, if company A physically uses organic cotton as a material input to its value chain, and it reports the emissions from the life cycle of the specific cotton that it physically uses, this would generally be considered an accurate statement of emissions.

Exploring this principle further in relation to market-based accounting, in the following thought experiment, company A uses a flight for business travel but pays company B to use video conferencing (instead of flying) and agrees to a contractual arrangement whereby company A reports the emissions from video conferencing and company B reports the emissions from flying. This would not appear to be accepted as an accurate reflection of either companies' emissions, even though there is no double counting of emissions, as company A is known not to have physically used video conferencing, and company B is known not to have physically used a flight.

Principle 1: if it is possible to identify a specific source that is physically used within the value chain of the reporting entity, then the reporting entity should report the emissions from that specific source.

Principle 2: allocation of emissions without double counting is not sufficient for accurate value chain inventories.

If it is not possible to trace the specific source that is physically used by a reporting entity, then generally, an average is used instead, based on the most disaggregated pool of sources to which physical traceability is possible (WBCSD/WRI 2011a; ISO 2020). For example, if company A cannot trace the specific source of steel that it uses, but it is possible to trace the steel used to a supply region, then, in the absence of other information, the average emissions for steel produced in that region should be used, rather than a more aggregated or global average. If company A reported its emissions using a global average rather than a more disaggregated average, generally, this would be considered a less accurate statement of its emissions.

Exploring this principle further in relation to market-based accounting, the following thought experiment considers the situation in which the reporting entity purchases attributes from outside the activity pool that physically serves the reporting entity. Company A purchases cement from a supply hub that distributes cement produced in Europe, and the company also purchases emission attributes from a source that is *outside* this physical activity pool, e.g. attributes for low-carbon cement produced in the USA.[2] Reporting the emissions for production in the USA would generally not be regarded as an accurate account of company A's value chain emissions, as it is not possible that company A physically used cement from the USA. As an extension to this thought experiment, if the purchase of the emission attributes caused an increase in the amount of low-carbon cement produced in the USA, a claim to have used US low-carbon cement would still not be regarded as accurate, as it is physically impossible that company A used the US cement.

Principle 3: if it is not possible to trace the specific source that is physically used, then, in the absence of an alternative basis for reporting the emissions from a specific source, an average for the most disaggregated pool of sources to which physical traceability is possible should be used.

Principle 4: using an emission rate for a source that could not have physically served the reporting entity would be regarded as inaccurate.

The following thought experiment explores the situation in which there is no traceability to a specific source,

[2] Certification or 'chain-of-custody' schemes that separate environmental attributes from the products that are physically used are sometimes referred to as 'book-and-claim' schemes. Certification or 'chain-of-custody' schemes that involve mixing materials that have certain environmental attributes with materials without those attributes are sometimes referred to as 'mass balance' schemes (GHG Protocol 2022b). Both have been used for market-based accounting.

though there is traceability to a broader activity pool, and the company purchases emission attributes from a source that is *within* the physical activity pool. Company A produces paper products that are disposed of at their end-of-life, and it is not possible to trace whether they are recycled, incinerated, or landfilled. Company A buys emission attributes from a recycling facility within the region where the products are disposed of, and, for the purposes of this thought experiment, buying the emission attributes does not increase the amount of recycling that occurs. If company A reports that all its products are recycled and uses the emission rate for recycling within its value chain inventory, this would generally not be regarded as an accurate account of value chain emissions. This appears to be because there is no physical or alternative causal relationship between the company and the specific emission rate that is claimed (as the company's action to buy emission attributes from the recycling facility did not cause a change in the amount of recycling).

Principle 5: using an emission attribute for a specific source within the physical activity pool is not accurate in the absence of a physical or other causal relationship to the specific emission rate that is claimed.

In the following thought experiment, there is no traceability to a specific source, but there is physical traceability to an aggregate activity pool, and there is also a causal relationship between the reporting entity and a specific emission rate within the activity pool. Company A buys coffee beans from a supply hub, and it is not possible to trace the coffee beans that company A physically uses to specific coffee farms. Company A engages with a specific farm that supplies the supply hub to plant shade trees and increase carbon sequestration on the farm.[3] In this thought experiment, the planting of the shade trees would not have occurred without company A's intervention. If company A reports the sequestration rate that it helped to achieve, this could be considered an accurate reflection of company A's value chain removals, as there is physical connectivity to the activity pool, and there is a causal relationship to the specific rate that is claimed.

However, it is important to note that norms and principles tend to exhibit differing degrees of acceptance, and it appears likely that claims based on direct physical use are more broadly accepted than claims based on alternative causal relationships (such as the engagement in the example above). It is possible that some stakeholders and users of GHG inventories would not regard alternative causal relationships as a sufficient basis for using a specific emission rate.

Principle 6: if physical traceability is only possible to a shared activity pool, the use of a specific emission rate within that pool may be accepted as an accurate reflection of the reporting entity's value chain emissions if there is a causal relationship between the reporting entity and that specific rate.

3.2 Two possible solutions for market-based accounting

Based on the analysis above, the following sets out two possible solutions to market-based accounting. The formal normative specification of each solution is provided, followed by an explanation of the solution.

3.2.1 Solution 1: physical attribution with separate intervention reporting

Normative specification

1. If traceability to the specific source physically used is possible, then the reporting entity shall report the emissions from that source. When physical traceability to a specific source is not possible, the average of the sources within the activity pool that physically serves the reporting entity shall be used.
2. Any changes in emissions caused by the reporting entity should be calculated using a consequential/intervention accounting method and shall be reported separately from the value chain inventory.

Figure 1 provides a representation of solution 1 as a decision tree, and Box 1 provides a worked example of both solutions 1 and 2.

Explanation Solution 1 is essentially to disallow the use of market-based accounting and instead use 'location-based' accounting (WRI 2015) within the inventory and to use consequential accounting to separately report changes in emissions caused by the reporting entity's actions.

The concept of an activity pool, as 'the set of emission sources which may physically serve the reporting entity', and the requirement that 'the average of the sources within the activity pool that physically serves the reporting entity shall be used' entails that temporally and geographically explicit average rates should be used. For example, hourly or more temporally granular average electricity emission factors for the grid serving the reporting entity[4] should be used, where these are available. The current guidance for the location-based method for scope 2 reporting (WRI 2015) is broadly

[3] Mitigation actions within the reporting company's own value chain is sometimes referred to as 'insetting' (Gallemore and Jespersen 2019; Acampora et al. 2023).

[4] There is on-going debate on how best to define the spatial boundaries of an interconnected electricity grid for the purposes of greenhouse gas accounting (Tranberg et al. 2019; He et al. 2021; Robinson and Sullivan 2022). We do not seek to resolve this debate here, but we note that based on the identified principles for accurate value chain

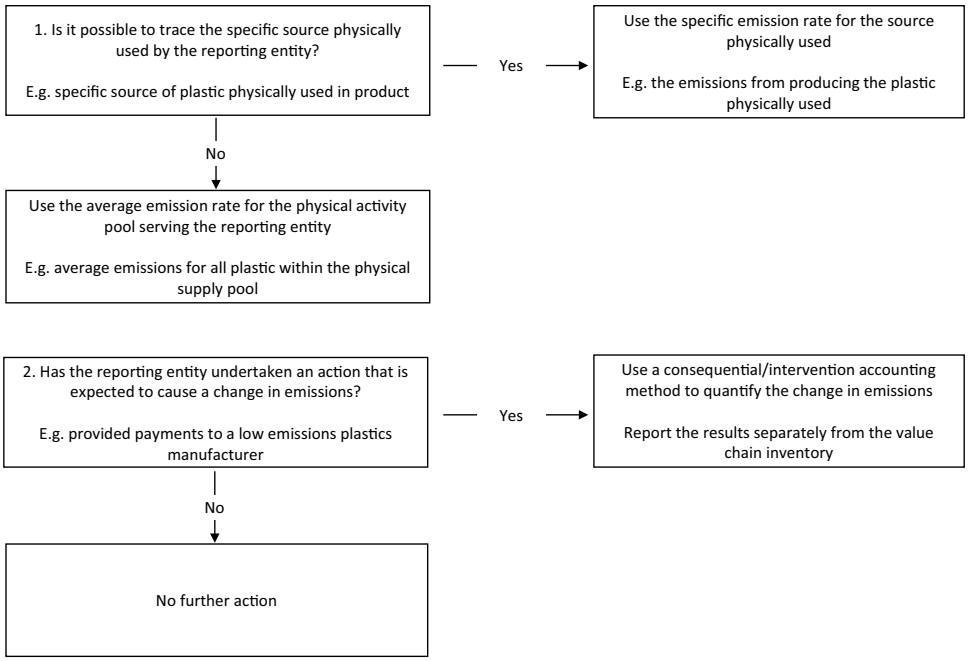

Fig. 1 Decision tree for implementing solution 1

consistent with paragraph 1 of solution 1, with the exception that it permits, but does not require, higher temporal granularity than annual average factors.

The consequential/intervention accounting methods referred to in paragraph 2 of solution 1 are methods that are designed to quantify the total system-wide change in emissions caused by an intervention (Ekvall and Weidema 2004; WRI 2014). Examples of this type of method are consequential LCA (Ekvall and Weidema 2004; Weidema et al. 2009), project-level accounting (WBCSD/WRI 2005; ISO 2019), and policy-level accounting (WRI 2014). These methods focus on identifying the marginal changes caused by an intervention and often include market-mediated effects that occur beyond the physical value chain of the entity undertaking the intervention (Brander 2016).

The intention of paragraph 2 of solution 1 is to provide information on the system-wide change in emissions caused by interventions undertaken by the reporting entity. For example, if the reporting entity purchases certificates from a renewable energy generator and doing so causes an increase in the amount of renewable generation, then a consequential/intervention accounting method can be used to calculate and report the reduction in emissions achieved. Any changes in emissions could be inside or outside the reporting entity's value chain and could be either a positive or negative change (i.e. increase or decrease in emissions).

It is highly important to emphasise that the results from any consequential analysis (under solution 1, paragraph 2) must be reported separately from the value chain inventory. A value chain inventory is an attributional form of accounting (Brander and Ascui 2016), and attributional and consequential values should not be combined, as the result will be neither an inventory of emissions nor an assessment of system-wide change caused by an intervention (Sandén and Karlström 2007).

3.2.2 Solution 2: market-based accounting with causality

Normative specification

1. If traceability to the specific source physically used is possible, then the reporting entity shall report the emissions from that source.
2. If there is no traceability to the specific source physically used within the value chain of the reporting entity, then the emission rate associated with a specific source may be reported under the following conditions:

   (a) The specific source is part of the activity pool that physically serves the reporting entity.
   (b) There is a causal relationship between the reporting entity and the emission rate that is claimed, such that the emission rate would not have occurred without the action of the reporting entity.

Footnote 4 (continued)

inventories, grid average emission factors should not include emissions from generation facilities that could not have physically served the reporting entity. For example, electricity generated in Hawaii should not be included in a grid average for any of the continental US states as there is no interconnector with Hawaii. ISO 14067 does not comply with this principle as it allows the use of energy attributes if they are from within the same country, even if there is no physical connection (ISO 2018a).

(c) The amount of activity data to which the specific emission rate is applied must not exceed the level of output or function caused by the reporting entity, at the specific source in question.

(d) The reporting entity has unique use of the emission rate, such that other reporting entities do not report the same emission within the same reporting category.[5]

3. If the reporting entity causes a new source to exist within the activity pool, then it should use the specific emission rate for that source.
4. If the reporting entity causes a change at an existing source within the activity pool, the emission rate shall be calculated using the following approach:
   (a) If the pre-intervention emission rate is lower than the average emission rate,[6] the following equation shall be used:

$$SRC = AR - (PR - IR) \quad (1)$$

where SRC is the specific emission rate caused,
AR is the average emission rate for the activity pool,
PR is the pre-intervention emission rate for the specific source,
IR is the intervention emission rate for the specific source.

(b) If the pre-intervention emission rate is higher than the average rate,[7] the reporting entity shall either use the intervention emission rate for the specific source or use the average rate for the activity pool.

5. All reporting entities that use an activity pool and do not claim a specific emission rate shall use a residual average emission rate for the activity pool, adjusted such that the rate does not include any specific emissions claimed.

Figure 2 provides a representation of solution 2 as a decision tree, and Box 1 provides a worked sample of both solutions 1 and 2.

Explanation Solution 2 accommodates principle 6, identified in Section 3.1. That is, if physical traceability is only possible to a shared activity pool, the use of a specific emission rate within that pool may be accepted as an accurate reflection of the reporting entity's value chain emissions if there is a causal relationship between the reporting entity and that specific rate.

Equation 1 ensures that reporting entities can only report the emission rate that they have caused and cannot select specific sources that already have lower than average emissions (or higher than average removals) and claim the full emission/removal rate by making minor additional improvements.

For example, if the average emissions for an activity pool supplying coffee beans are 1 $kgCO_2$/unit, and the pre-intervention emission rate for a specific farm is 0.8 $kgCO_2$/unit, and the intervention emission rate at that specific farm is 0.7 $kgCO_2$/unit, then the reporting entity can only claim a specific emission rate of 0.9 $kgCO_2$/unit (1 − (0.8 − 0.7) = 0.9 $kgCO_2$/unit). This represents the rate with which the reporting entity has a causal relationship.

It is important to note that although Eq. 1 involves the calculation of the change between a baseline (pre-intervention scenario) and the intervention scenario, this does not contravene the principle that attributional inventories should only count physical flows and should not include values for *avoided* physical flows (Ekvall and Andræ 2006; Brander and Wylie 2011; Brandão et al. 2021). The output from Eq. 1 is an emission rate rather than a value for an avoided emission.

Paragraph 4b under solution 2 ensures that the emission rate claimed is not lower than the lowest rate for any source within the activity pool and is not lower than zero and becomes a negative number.[8] For example, without paragraph 4b, if the average emissions rate is 1 $kgCO_2$/unit, and the pre-intervention rate is 2 $kgCO_2$/unit, and the intervention emission rate is 0.5 $kgCO_2$/unit, then the specific emission rate would be − 0.5 (which is not physically possible for an emission rate). The purpose of solution 2 is to identify emission rates with which the reporting entity has physical connectivity and a causal relationship, and emission rates below those that exist, or emission rates below zero, are not possible rates.

The concept of an activity pool and the requirement that the 'specific source is part of the activity pool that physically serves the reporting entity' (paragraph 2a under solution 2) entails physical deliverability and temporal matching between the value chain activities of the reporting entity and the specific emission rate claimed. For example, it is not possible to use an attribute certificate from electricity generation in the summer for electricity consumption that occurs in the winter, as this generation could not have served this consumption. Similarly, it is not possible to use an attribute certificate from electricity generation in Iceland for electricity consumption in Spain, as this generation could not have served this consumption.

[5] The term 'reporting category' refers to either types of GHG accounting method, e.g. life cycle assessment or corporate-level inventories, or to reporting categories within GHG accounting methods, e.g. scopes 1 and 2.

[6] Or in the case of sinks, if the pre-intervention removal rate is greater than the average removal rate.

[7] Or in the case of sinks, if the pre-intervention removal rate is less than the average removal rate.

[8] Or in the case of sinks, it does not exceed the highest rate for any sink.

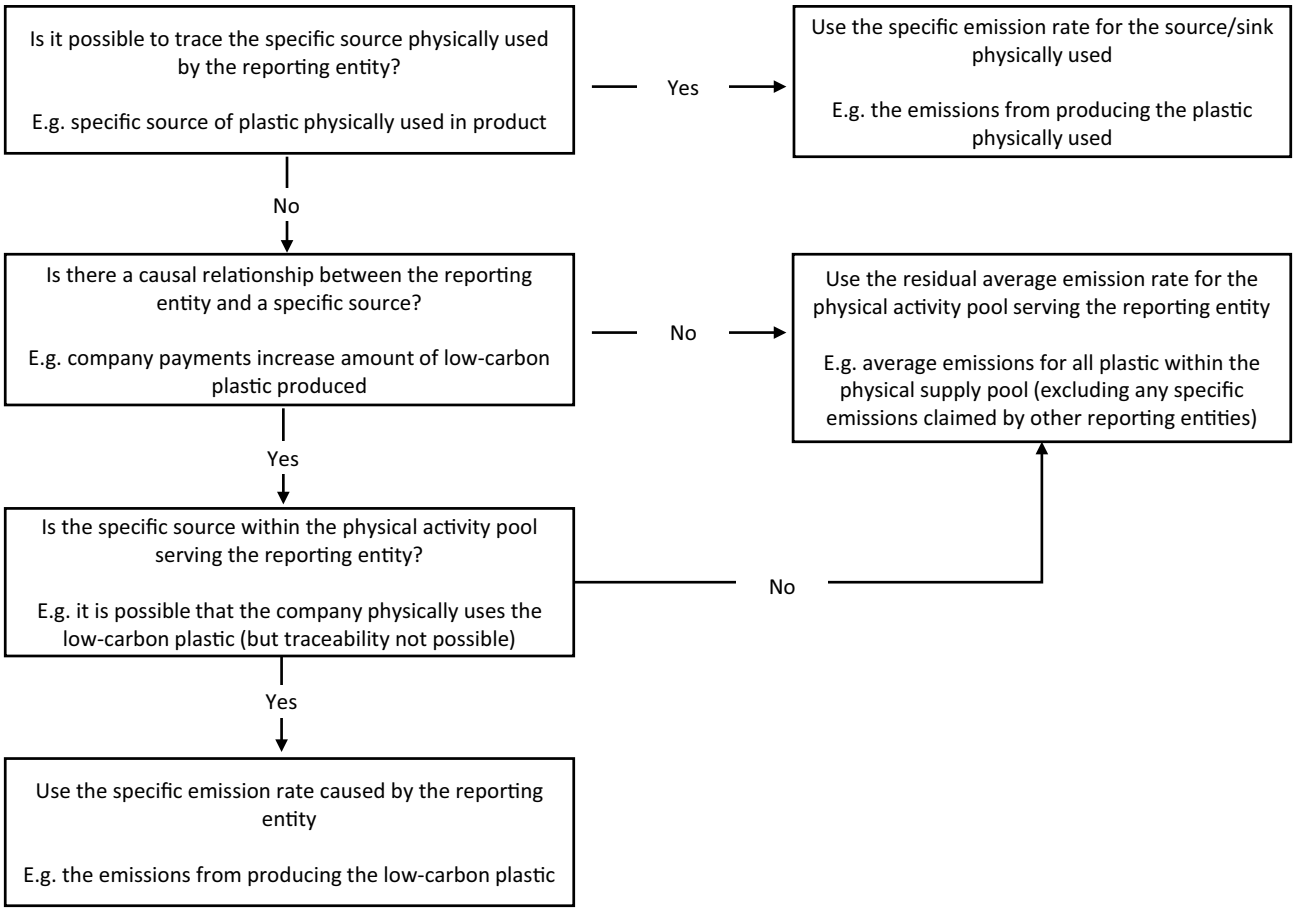

Fig. 2 Decision tree for implementing solution 2

The requirement that the 'amount of activity data to which the specific emission rate is applied must not exceed the level of output or function caused by the reporting entity, at the specific source in question' (paragraph 2c under solution 2) entails that the amount of emissions reported at a specific rate must match the amount of activity caused by the reporting entity at that rate. For example, it is not possible to cause 1 MWh of renewable power generation and apply the associated specific emissions rate to 1000 MWhs of electricity consumption.

Box 1. Example of the application of Solution 1 and Solution 2 A manufacturing company purchases plastic granules, which are sourced from a supply hub, and it is not possible to trace the plastic granules that are physically used back to a specific supplier within the supply pool. The average emissions for granules from the supply pool are 6 $kgCO_2$/kg granules. The manufacturer engages with one of the granule producers in the supply pool and provides the finance for upgrading and improving the energy efficiency of the factory producing the granules. The pre-intervention emissions for this producer were 7 $kgCO_2$/kg granules, and the post-intervention emissions are 5 $kgCO_2$/kg granules. The granule producer makes 50,000 t of granules per year, and the improved efficiency applies to total production. The manufacturing company uses 25,000 t/yr. This information is summarised below.

Description	Value	Units
Average emissions from granules in supply pool	6	$kgCO_2$/kg granules
Pre-intervention emissions from specific producer	7	$kgCO_2$/kg granules
Post-intervention emissions from specific producer	5	$kgCO_2$/kg granules
Annual production from specific granule producer	50,000	T granules/yr
Annual purchase by the manufacturer	25,000	T granules/yr

Solution 1: the manufacturing company would use the average emission factor of 6 $kgCO_2$/kg granules and report the embodied emissions of its purchased granules as 150

tCO_2 (25,000 × 6/1000 = 150). The manufacturing company would also separately report the total change in emissions caused by its intervention using a consequential accounting method, which would be − 100 tCO_2 (50,000 × (5 − 7)/1000 = − 100).

Solution 2: the manufacturing company would use an emission factor of 5 $kgCO_2/kg$ granules and report the embodied emissions of its purchased granules as 125 tCO_2 (25,000 × 5/1000 = 125). This is the rate with which the manufacturing company has physical connectivity and a causal relationship.

4 Discussion

4.1 Advantages and disadvantages of solution 1

An advantage of solution 1 (specifically the requirement in paragraph 2) is that it addresses broader limitations with attributional inventories, in particular, the limitation that attributional inventories do not reflect the total change in emissions, either positive or negative, caused by the reporting entity's actions (Plevin et al. 2014; Brander et al. 2019; Brander 2022a):

Example 1: electricity demand-side management avoids the marginal generation technology that would have been dispatched to meet the marginal unit of demand, and the use of marginal emission factors within a consequential method conveys this change in emissions (Regett et al. 2018).

Example 2: avoided emissions caused by a product or service, e.g. telecommunication services avoiding business travel (Bieser et al. 2023), are not reflected within a scope 1, 2, and 3 inventory of the company providing the product or service, and separate reporting of avoided emissions would convey this information.

Example 3: companies can cause indirect or market-mediated effects, such as indirect land use change, that occur outside the companies' inventory boundaries (WBCSD/WRI 2022b). Separate reporting of system-wide changes in emissions would convey information on these indirect or market-mediated effects.

Another advantage of solution 1, paragraph 2, is that it is broadly consistent with existing guidance within the *GHG Protocol Corporate Accounting and Reporting Standard*. This standard states 'In cases where accuracy is more important [i.e. for understanding the change in emissions caused by a company's actions], it may be appropriate to undertake a more detailed assessment of the actual reduction using a project quantification methodology' (WBCSD/WRI 2004, p. 59). The standard also states 'These reductions [avoided emissions that occur outside the inventory boundary] may be separately quantified, for example using the GHG Protocol Project Quantification Standard, and reported in a company's public GHG report under optional information' (WBCSD/WRI 2004, p. 61). Solution 1, paragraph 2, is also consistent with the concept of 'Pillar B' within Carbone 4's guidance for carbon neutrality, which relates to 'reducing other's emissions' (Carbone4 2020). However, it is important to note that solution 1, paragraph 2, goes beyond the GHG Protocol and Carbone 4 guidance by recommending that reporting entities should report on *increases* in emissions caused by the entity's actions, as well as decreases.

One disadvantage of solution 1 is that some existing target-setting practices and programmes, such as the Science Based Targets Initiative (SBTi 2021), focus on reducing emissions within the inventory boundary and tend not to recognise or incentivise reductions caused outside the inventory boundary (i.e. there is currently limited incentive to act on the information required in solution 1, paragraph 2). However, this could be addressed by disclosure or target-setting programmes giving more attention to the system-wide changes in emissions caused by company activities, as is the case with 'Pillar B' within Carbone 4's guidance (Carbone4 2020).

Another disadvantage of solution 1 is that quantifying system-wide changes in emissions can be complex and involve modelling choices that could be manipulated by reporting companies to overstate the reductions they cause (or understate any system-wide increases in emissions). For example, consequential/intervention methods involve quantifying change relative to a hypothetical baseline, and the selection of the appropriate baseline is often open to interpretation or manipulation (Cames et al. 2016). One action to mitigate this problem is to require transparent reporting on the assumptions and evidence used in the quantification exercise.

4.2 Advantages and disadvantages of solution 2

One advantage of solution 2 is that it is aligned with the existing paradigm of primarily focusing target setting on emissions within the value chain (SBTi 2021). A further advantage is that it may support the development of market-based instruments that genuinely cause the attributes that they convey (Gold Standard 2021).

One disadvantage of solution 2 is that it may be difficult to implement robust tests for causality, i.e. proving that a specific emission rate would not have occurred in the absence of the action of the reporting entity, especially

as reporting entities will have an incentive to manipulate such tests (Greiner and Michaelowa 2003). This is similar to the issue identified above for consequential/intervention accounting in solution 1, i.e. the difficulty with proving a hypothetical baseline. As above, this issue can be mitigated to some extent by requiring transparent reporting on the assumptions and evidence used.

Another potential challenge with solution 2 is the need to precisely define what counts as a 'new source' in order to operationalise the requirement that 'If the reporting entity causes a new source to exist within the activity pool then, it should use the specific emission rate for that source' (paragraph 3). For example, it may be difficult to determine whether retrofitting or repowering at an existing site constitutes a wholly new source or only a change to an existing source.

A further disadvantage of solution 2 is that it may disincentivise improved traceability; that is, there will be an incentive to maintain non-traceability within shared activity pools, even though traceability may be technically feasible, in order to continue using market-based accounting.

A further limitation with solution 2 is that it does not address the problem that changes in emissions outside the inventory boundary caused by the reporting entity are not shown, including both positive and negative changes. This entails that in addition to solution 2, a further reporting requirement would be needed, similar to paragraph 2 in solution 1.

A further disadvantage of solution 2 is that it requires the calculation of residual average emission rates in order to avoid double counting. This would require the administration of a process for tracking specific emission rate claims and the calculation and publication of residual average rates (Holzapfel et al. 2023).

4.3 Further points for discussion

Applying the six principles identified in Section 3.1 to the current scope 2 guidance for market-based accounting shows that the guidance contravenes these principles in two ways. Firstly, the guidance allows the use of attributes from sources that could not have physically served the reporting entity (i.e. contrary to 'principle 3'), as also noted by Robinson and Sullivan (2022) in the case of the USA. Secondly, the current scope 2 guidance allows the use of attributes for a specific emission source, e.g. a wind farm, even when there is no physical or causal relationship that serves as the basis for using the specific emission rate (i.e. contrary to 'principle 5'). In both cases, the resulting GHG accounts would generally not be considered an accurate reflection of the reporting company's value chain emissions. It is worth noting that the current scope 2 guidance avoids double counting of emission attributes by requiring unique ownership of attributes and the use of residual grid mix emission factors for any electricity purchases not covered by energy attribute certificates (WRI 2015). However, as per 'principle 2', the allocation of emissions without double counting is not sufficient for accurate value chain inventories.

That the current scope 2 guidance contravenes existing norms for what constitutes accurate GHG accounts is also evidenced by the numerous publications that question the accuracy of current scope 2 market-based accounting practice, including media articles (Politiken 2020, 2022; Financial Times 2021; Wall Street Journal 2022), commentaries (Corradi 2018; Gowdy 2018), market analyst reports (Lazard Asset Management 2020; S&P Global 2021; Bloomberg 2022; Cornwall Insights 2023), and academic articles (Brander, Gillenwater and Ascui 2018a, b; Monyei and Jenkins 2018; Bjørn et al. 2022).

In defence of current market-based accounting practice, some proponents suggest that the legal status of emission attributes entails that market-based accounting is accurate, as the owner of an attribute is legally entitled to make a claim based on the attribute. For example, in the USA, a renewable energy certificate conveys the right to claim the use of renewable energy, even if it is physically impossible that the owner of the attribute used renewable energy (Jones et al. 2015, 2023). However, the norms or principles for what constitutes an *accurate* claim appear to be independent of the legal entitlement to make the claim. For example, as noted above, the EU's Renewable Energy Directive allows member states to report, for legal compliance, that renewable energy is 'four times its energy content when supplied to road vehicles' (European Commission 2018, p. 127). Nevertheless, this does not entail that it is actually true (i.e. accurate) that renewable energy has four times its own energy content, which is a physical impossibility.

There have been two other prominent proposals in response to the GHG Protocol's recent consultation on its scope 2 guidance (GHG Protocol 2023), and the following provides a brief analysis of these proposals based on the six principles identified in this paper. One proposal is from the Emissions First partnership (EFP), which suggests calculating an 'induced' emissions figure based on electricity consumption multiplied by marginal emission factors and an 'avoided' emissions figure based on the purchase of energy attribute certificates (EACs) multiplied by marginal emission factors (He et al. 2021; Emissions First Partnership 2023). The 'avoided' figure is then subtracted from the 'induced' figure to give an overall scope 2 result. Although there may be merits to this approach in terms of incentivising actions that reduce emissions, it does not appear to be consistent with the principles for an accurate value chain inventory. The proposal allows the use of EACs from sources

that could not have physically served the reporting entity, i.e. from outside the activity pool,[9] which contravenes principle 4 ('using an emission rate for a source that could not have physically served the reporting entity would be regarded as inaccurate'). Moreover, it is not clear whether the EFP proposal includes any causality requirement on the use of EACs, the absence of which would contravene principle 5 ('using an emission attribute for a specific source within the physical activity pool is not accurate in the absence of a physical or other causal relationship to the specific emission rate that is claimed'). The absence of a causality requirement would also undermine the EFP's stated aim of incentivising action that reduces emissions.

The second alternative prominent proposal submitted to the GHG Protocol's scope 2 consultation is from Google. This proposal suggests introducing constraints on the use of EACs such that they are geographically and temporally matched to consumption (Google 2023). This proposal therefore has similarities to solution 2 in this paper, as the emissions rate claimed would be restricted to sources within the activity pool serving the reporting entity. However, the Google proposal does not include a causality requirement and so contravenes principle 5. It is possible that restricting the availability of eligible EACs via geographical and temporal matching could increase the price of certificates and thereby increase the likelihood of a causal relationship between the reporting entity and the emission rate claimed (IEA 2022). Nevertheless, in the absence of an explicit causality requirement, inaccurate claims would be permissible under the Google proposal.

A final important point to note is that although this paper focuses on corporate GHG inventories, the principles identified apply equally to product-level GHG footprints and also attributional life cycle assessment more broadly, i.e. to any impact category and not just GHG emissions. Indeed, the inaccuracy of market-based accounting arises at the life cycle inventory stage, which aims to inventory the material and energy flows to and from the processes in the life cycle of a product (ISO 2020). For example, if renewable electricity is not physically used within the life cycle of a product, then the life cycle inventory will not be viewed as accurate if it includes renewable electricity, regardless of the purchase of market-based instruments. This means that the requirement for market-based accounting within ISO 14067 (ISO 2018a) and the PEF guidance (European Commission 2012) will produce results that would not be viewed as accurate, and these standards should be amended at the earliest opportunity.

[9] He et al. (2021) encourages companies to prioritise EACs that are both low cost and from locations with high marginal emissions factors and considers the 'avoided' emissions able to 'offset' the 'induced' emissions.

5 Conclusions

In order to inform the debate on the future of market-based accounting, this paper uses thought experiments to identify the following six principles for accurate value chain inventories:

1. If it is possible to identify a specific source that is physically used within the value chain of the reporting entity, then the reporting entity should report the emissions from that specific source.
2. Allocation of emissions without double counting is not sufficient for accurate value chain inventories.
3. If it is not possible to trace the specific source that is physically used, then, in the absence of an alternative basis for reporting the emissions from a specific source, an average for the most disaggregated pool of sources to which physical traceability is possible should be used.
4. Using an emission rate for a source that could not have physically served the reporting entity would be regarded as inaccurate.
5. Using an emission attribute for a specific source within the physical activity pool is not accurate in the absence of a physical or other causal relationship to the specific emission rate that is claimed.
6. If physical traceability is only possible to a shared activity pool, the use of a specific emission rate within that pool may be accepted as an accurate reflection of the reporting entity's value chain emissions if there is a causal relationship between the reporting entity and that specific rate.

Based on these principles, we then propose two possible solutions to market-based accounting. The first is to eliminate the use of market-based accounting and instead require that reporting entities disclose any changes in emissions caused by their actions using consequential/intervention accounting methods. The second is to allow market-based accounting but with physical connectivity and causality constraints (and to use residual average factors to avoid double counting). It is worth highlighting that the proposed solutions provide a consistent approach to market-based accounting; are equally applicable across scopes 1, 2, and 3; and are also equally applicable to other forms of environmental inventory accounting such as LCA.

As a final concluding remark, we recognise that part of the motivation for market-based accounting is to create markets for environmental attributes, which in turn *may* support reductions in emissions. However, if the intention is to create accurate inventories of value chain emissions, it is essential to reflect physical and causal realities. As noted above, inventories are highly useful for purposes such as holding

entities to account for their value chain emissions, but they do not show changes that occur outside the inventory boundary (Brander et al. 2019). In addition to inventory reporting, we recommend that alternative methods are used to report on the system-wide change in emissions caused by company actions and that this information is reported separately.

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Declarations

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