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KBS Research Impact Papers, No. 1

Emissions gaming?

A gap in the GHG Protocol may be facilitating gaming in accounting of GHG emissions

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A gap in the GHG Protocol may be facilitating gaming in accounting of GHG emissions

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Abstract

The framework for calculating firms' greenhouse gas emissions via the GHG Protocol is highly complex. It involves the collection and management of large datasets on companies' activities, and both scientific and estimation uncertainty in translating such activities into emissions estimates. Moreover, there are substantial degrees of freedom created by the existence of multiple calculation methods and emission factor databases, which deliver markedly different emissions estimates for the same underlying activity data inputs. For instance, emission factors in the UK-Defra database are on average 10% lower than those in the US-EPA database, with substantially more variation. Preparers of GHG emissions calculations are required to exercise judgement in selecting the appropriate approach to employ. This framework, we argue, is ripe for being gamed and is unlikely to produce accurate estimates of companies' true emissions in a durable way. We show, via a pilot study using proprietary data, that these differences are material. If gaming opportunities are fully exploited, actual emissions for some firms could be several times larger than those currently reported. We offer five policy recommendations aimed at making the calculation and reporting of GHG emissions robust.

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1. Introduction

There appears to be a gap in the GHG Protocol that allows for errant practices in the calculation of greenhouse gas (GHG) emissions and unintended results. The GHG Protocol was developed by the World Resources Institute (WRI) and the World Business Council for Sustainable Development (WBCSD) and is the most common and widely respected basis of GHG accounting and reporting (Kaplan and Ramanna, 2021). The Protocol prescribes various methodologies and the use of specified datasets of emission factors to calculate GHG emissions. Datasets of emission conversion factors are updated periodically to accurately reflect the current emissions profile of a given activity or source. The United Nations Framework Convention on Climate Change (UNFCCC) approves three datasets for global use under the GHG Protocol (UNFCCC, 2023):[1] UK Department for Environment, Food and Rural Areas (UK-Defra) and US Environmental Protection Agency (US-EPA) and EXIOBASE, a global Environmentally Extended Input-Output (EEIO) database, used by the European Union (EU) and multiple countries worldwide. Additionally, a further 43 national databases of implied emission factors are used in National Emissions Inventories (NEIs) and are approved under the Protocol.[2]

Crucially, the Protocol does not prescribe which datasets of emission factors should be used, allowing preparers and users of GHG emission calculations to maximise their desired outcomes. We find that the US-EPA dataset reports roughly 10% greater GHG emissions than its UK counterpart.[3] Even if preparers want to use national datasets this is not possible for over 150 United Nations (UN) member states. It also presents challenges for preparers of GHG emission calculations working across borders for multinational corporations, for example. The three global datasets become the default option (ghgprotocol.org).[4] In short, the GHG Protocol is gameable (Lawrence, 2007). This study quantifies the differences between two of the most used global datasets of emission factors i.e., UK-Defra and US-EPA and calculates the GHG emissions of three case companies to illustrate the game-ability of the GHG Protocol and the potential effects on environmental and financial materiality.

Humankind is attaching great weight to the quality of GHG accounting and reporting.[5] The IPCC (2023) has identified a need to accelerate urgent action to reduce GHG emissions in line with the target of limiting global warming to 1.5°C by 2030 (or reducing it to that level thereafter). However, the same IPCC report (2023) identified that projected GHG emissions from policies and finance flows (already implemented and planned) fall short of the levels needed to meet climate goals. The accounting and reporting of GHG emissions in the public and private sector are foundational to policy on climate change which has targeted private sector funding as a critical mechanism of climate action (Jia, Ranger, and Chaudhury, 2022). The disclosure of GHG emissions is the focus of new regulations being introduced in a coordinated and networked ecosystem worldwide (Bowman, 2022). GHG accounting is also foundational to ambitions for the introduction of carbon taxes and carbon pricing (Stern, 2011). The European Union's Carbon Border Adjustment Mechanism (CBAM) foreshadows the importance of GHG accounting and reporting as a basis of carbon taxation (European Commission, 2022). There are increasing calls for regulation of preparers and standardisation of methodologies and calculation (UN, 2023; HM Treasury, 2023; Hancock and Bryan, 2023). Against this background, this study is motivated by a desire to shine a light on the inherent game-ability of the GHG Protocol.

The strengths and limitations of the GHG Protocol have been discussed by scholars (e.g., Cano et al., 2023; Rajgopal, 2022; Kaplan and Ramanna, 2021). There is consensus that GHG emissions calculated using the GHG Protocol are inherently uncertain. In some cases, this is due to lack of data and/or the source of data, in others it is assumptions used, in others still it is judgements made about the boundary of the analysis of a business activity. Scholars have recommended theoretical methods to improve the statistical uncertainty inherent in the GHG Protocol (for example, Perkins and Suh, 2019; Marujo et al., 2022). Researchers have also examined the uncertainty of GHG emissions from sectors such as energy, industrial process and agriculture (Kristin and Winiwarter, 2001b); from specific sources such as dairy cow systems (Lee et al., 2020) and forestry (Monni et al., 2007); from spatial distribution of emissions (Bun et al., 2010); in life cycle emissions (Venkatesh et al., 2011); in parameters (i.e., activity data and emission conversion factors) (Monni, Syri and Savolainen, 2004). This study complements this work by empirically illustrating the concept of emissions gaming.

> **There is uncertainty in the application of the GHG Protocol, which combined with other incentives means that GHG emissions can (and likely are) gamed**

The concept of emissions gaming is based on potential conflict between goals for preparers, reporters, and users. For preparers there is a potential conflict between calculating GHG emissions and revenue from the sale of carbon offsets i.e., the higher the emissions estimated, the more offsets required, the higher the revenue. Preparers may also be incentivised by rating shoppers to 'low-ball' emissions. For reporters, there is a potential conflict between restating emissions incurred (e.g., as science improves and as estimates become more accurate) and a desire for reputational gain by reporting ever reducing GHG emissions against a baseline 'fixed' in a transition plan to Net Zero GHG emissions. For users there is a potential conflict between having confidence in reported emissions and recognising uncertainties and inevitable estimation inherent in the system of GHG accounting and reporting. In sum, there is uncertainty in the application of the GHG Protocol, which combined with other incentives means that GHG emissions can (and likely are) gamed.

If emissions gaming is occurring, how material could it be? To explore this question, we run a pilot study using proprietary activity data from three companies. We find stark differences between the largest and smallest feasible emissions estimates using the calculation methods and databases permitted under the GHG Protocol. On average across the three companies, the maximum estimate is between 4.6 and 6.7 times the minimum. If these firms are representative of the SME sector in the United Kingdom as a whole, our results suggest that this sector's actual emissions could be materially higher than the 146 million tonnes (CO2e) currently reported.

We offer a set of five policy recommendations for those charged with policymaking in this area to consider. These recommendations echo calls for reform and are aimed at making the calculation of GHG emissions and their reporting robust (e.g., UN, 2023; HM Treasury, 2023):

1. Regulate preparers of GHG emissions calculations and require external audit.
2. Introduce a new metric that requires reporting entities to disclose the proportion of all scopes that are covered and assured (ISAE 3000).
3. Require reporting entities to disclose up-front methods and datasets used in calculations and to restate historical data to aid comparison.
4. Require reporting entities to calculate and disclose emissions using datasets that are representative of where the emissions producing activity takes place. Reporting entities should also report against different emission factor datasets, including both local and global.
5. National agencies should investigate categories of emissions factors with large variances across datasets.

The remainder of this paper is organised as follows: an explanation of the methodology for the calculation of GHG emissions (Section 2); a discussion of practical issues confronted when operationalising the GHG Protocol, including the differences between the UK-Defra dataset of emission factors and its US counterpart US-EPA[6] (Section 3); results of a pilot study which demonstrates the differences in reported GHG emissions depending on whether UK-Defra or US-EPA is used (Section 4); an examination of the incentives the permitted use of different datasets presents for errant practices (Section 5); conclusion and policy recommendations (Section 6). The annex contains a full literature review (Annex 1), a detailed description of the GHG Protocol (Annex 2), and a list of national datasets of emission factors (Annex 3). The terms GHG and CO2e emissions are used inter-changeably throughout.

2. GHG calculation and methodology

The first version of the GHG Protocol Corporate Standard was published in 2001; it was revised in 2004 and updated with additional guidance for preparers to account for emissions from energy purchased and created on companies' value chains.

The GHG Protocol sets out the steps for calculating a firm's GHG emissions:

- identify activities that are sources of emissions (Section 2.1.)
- decide on methodology as per scope of emissions i.e., Scope 1, 2 or 3 (Section 2.2.)
- collect or estimate data on activities
- multiply the activity data by the relevant emission conversion factor, which measures the amount of greenhouse gases the activity emits, measured in carbon dioxide equivalent or 'CO2e' units (Section 2.3.)
- aggregate individual activity emissions to the company level.

That is, the quantity of GHG emissions of firm '*i*' is the product of its activities (*j*) that cause emissions and the associated conversion factors, measured in CO2e units, and summed across all activities:

$$\text{Firm } i \text{ GHG emissions (kg)} = \sum_j \text{activity}_j \text{ (units)} \times \text{emission conversion factor}_j \text{ (kg/unit)} \times \text{GWP}$$

This calculation requires data on activities such as litres of fuel consumed, electricity usage or distance travelled. It also requires information on the relevant emission conversion factors, which convert measurable activity into an estimate of the quantity of greenhouse gases emitted. Finally, it requires an estimate of the global warming potential (GWP) of different greenhouse gases, which are typically converted into CO2e units.

In this section, we discuss the standards set up by the GHG Protocol governing activity data, calculation methodologies, and GWP values.

2.1. Categorising emissions: Scopes 1, 2 and 3

The GHG Protocol categorises GHG emissions into three 'scopes' for accounting and reporting purposes.

Scope 1 greenhouse gas emissions are direct emissions from sources that are controlled or owned by the company. This includes emissions from stationary combustion, mobile combustion, physical or chemical processes, and intentional and unintentional releases. For example, activity data for Scope 1 will include the quantity of fuels burned on-site, the quantity of fuel used in company-owned vehicles, and the quantity of gases used in production processes.

Scope 2 emissions arise from the generation of purchased energy consumed by the company, with the quantity of energy consumed as the activity data input.

Scope 3 includes all other indirect emissions from a company's upstream and downstream activities. It comprises emissions from across the value chain. Upstream Scope 3 emissions include those from purchased goods and services, capital goods, fuel- and energy-related activities not included in Scope 1 or 2, upstream transportation and distribution, waste generated in operations, business travel, employee commuting, and upstream leased assets. Downstream Scope 3 emissions include those from transportation and distribution, processing of sold products, use of sold products, end-of-life treatment of sold products, leased assets, franchises, and investments. Activity data inputs for Scope 3 will include employee commuting distances and modes of transportation, business travel, the quantity of waste generated and method of disposal, the quantity and type of purchased materials and fuels, and the quantity of goods and services purchased.

It is important to note that, while these scopes are mutually exclusive at the reporting company level, once we move to the sector or economy-wide level there is double counting inherent in this approach. For example, one firm's Scope 3 emissions will be another firm's Scope 1 or 2 emissions.

2.2. Methods for calculating greenhouse gas emissions

There is a hierarchy of permissible approaches recommended by the GHG Protocol for calculating Scope 1, 2 and 3 emissions. We provide an overview of these approaches in Figure 2.1.[7]

Figure 2.1. Hierarchy of calculation methods under the GHG Protocol

	If the primary data are available	If the activity data are available	If the activity data are unavailable for Scope 3
Scope 1	**Specific-based method** The reporting company's activity data × Emission factors calculated directly by the reporting company	**Average-based method** The reporting company's activity data × Emission factors from approved external sources*	
Scope 2	**Market-based method** The reporting company's purchased energy × Emission factors provided directly by the power generator	**Location-based method** The reporting company's purchased energy × Grid average emission factors	
Scope 3	**Specific-based method** The reporting company's activity data × Emission factors from reporting the company's value chain	**Average-based method** Data from the reporting company and companies on its value chain × Emission factors from approved external sources*	**Spend-based method** Expenditure data of the reporting company × Emission factors from approved external sources

*External data sources include published databases, government statistics, and literature studies

- Green represents the highest level of anticipated accuracy
- Orange represents the mid-level of anticipated accuracy
- Pink represents the lowest level of anticipated accuracy

In the case of Scope 1 and Scope 3 emissions, the Protocol recommends that companies use the so-called 'specific-based' method. For Scope 1, the specific-based method entails multiplying the reporting company's activity data with the specific emission conversion factors estimated and reported by the company. For Scope 3, the calculations using the specific-based method apply the specific factors estimated and reported by the reporting company's value chain partners, which can include transportation carriers, suppliers, and others on the value chain.

If the data are not available to implement the preferred specific-based method, e.g., activities have not been measured and recorded, the GHG Protocol recommends other approaches. These include the so-called 'average-based' method for Scopes 1 and 3, and the 'spend-based' for Scope 3. The average-based method multiplies the activity data of the company, and those on its value chain in the case of Scope 3, with estimates of industrial averages of CO2e for the activity in question. These are provided by approved external sources, including open databases (e.g., IPCC Emissions Factor Database), government statistics (e.g., UK-Defra and US-EPA), literature studies, and industry associations.

As the name suggests, the spend-based method instead calculates Scope 3 emissions based on a company's expenditure on goods and services and their associated spend-based conversion factors.[8] These factors are derived from so-called 'Environmentally Extended Input-Output' or EEIO models,[9] which combine data from input-output tables and hence economic flows between sectors with information on GHG emissions by sector or product category. The result is an estimate of the GHG emissions per monetary unit of production for each sector or product category in the economy.

The spend-based method is the least accurate of the approaches and is viewed in the GHG Protocol as a fallback for when more precise activity data are not available. Examples of spend data can include expenditure on purchase, transportation, and storage of raw materials, on capital goods, on extraction, production, and the transportation of fuels, on waste disposal services, and on business travel and employee commuting.[10]

Turning to Scope 2, the preferred approach is the so-called 'market-based' method. This is based on the specific greenhouse gas emissions of the generators from which a company contractually purchases its electricity. It involves using emission conversion factors derived from supplier-specific data in the contractual instruments. If the supplier-specific data are available, preparers should report two Scope 2 results according to the market-based and location-based methods. Otherwise, they can report only one results based on the 'location-based' method. This method calculates emissions based on the average emissions from energy generation occurring within a specific geographical location and defined period.

2.3. Conversion of non-CO2 greenhouse gases to CO2e

It is typical to aggregate greenhouse gas emissions when converted into units of CO2e using so-called 'Global Warming Potential' or GWP values. This is based on an estimate of the global warming impacts of different greenhouse gases based on their ability to absorb energy ('radiative efficiency'), and how long they remain in the atmosphere ('lifetime'). It is a metric that compares the amount of heat trapped by a given amount of greenhouse gases in the atmosphere to the amount of heat trapped by the same amount of CO2 over a specific period (typically 100 years). CO2 serves as the numeraire, with a GWP of unity; other greenhouse gases like methane (CH4) and nitrous oxide (N2O) have much higher GWP values because they can cause stronger heat-trapping effects (EPA, 2023).[11] To convert a quantity of a greenhouse gas to CO2e, the quantity is simply multiplied by its GWP.

The Intergovernmental Panel on Climate Change (IPCC) updates GWP values regularly in its Assessment Reports (AR) as the understanding of greenhouse gases' atmospheric lifespan and radiative efficiency improves. For example, the GWP value for methane was revised down to 265 in IPCC AR 5 (IPCC, 2014) from 298 in IPCC AR 4 (IPCC, 2007). According to the GHG Protocol, reporting companies should either use the IPCC GWP values agreed upon by the United Nations Framework Convention on Climate Change (UNFCCC) or the most recent GWP values released by IPCC. The degree to which users of GHG data in the financial sector or in industry are generally aware of this critical nuance is questioned.

2.4. Misapplication of GHG Protocol

Despite the attempted clarity of the GHG Protocol, it is likely that the framework is being misapplied in some instances. A recent market research survey of practices at environmental impact platforms ('preparers') found that, despite claiming to follow the Protocol, eight out of the 17 firms surveyed use the spend-based method to calculate their clients' Scope 1 and 2 emissions (KBS, 2023) – an approach that is not permitted by the Protocol in the case of Scope 1 and 2 emissions.

3. Uncertainty in reported emissions

Given the range of methods and datasets available for calculating CO2e emissions, and the uncertainty inherent in all these calculations, it is best to think of a company's reported emissions as a noisy estimate of the true underlying level. This uncertainty includes: (a) that relating to a company's records of its activity data over the reporting window; (b) the estimation uncertainty associated with measuring the GHG emissions associated with different activities; (c) the scientific uncertainty associated with our less than perfect understanding of the global warming potential of different greenhouse gases; and (d) the likelihood of restatements of emissions figures, which may be extensive and frequent.

While the academic literature has focused to date on quantifying aspects of this estimation and scientific uncertainty (see Annex 1 for a review of this literature), less attention has been given to the behavioural implications of introducing this spectrum of permissible approaches. Specifically, our concern is whether companies – or the preparers employed by them to calculate their emissions – will be incentivised to use methods or datasets to achieve ends that are not perfectly aligned with producing an unbiased estimate of the emissions in question. This is a form of regulatory arbitrage, not dissimilar to cases where banks choose favourable parameter assumptions to optimise risk weighted asset calculations based on internal models.[12]

In this section, we analyse one specific aspect of this problem: the difference in emission factors between the databases published by the UK's Department for Energy, Food and Rural Affairs (Defra) and the US's Environmental Protection Agency (EPA). As described in the introduction, these databases, alongside EXIOBASE, a global Environmentally Extended Input-Output (EEIO) database of spend-based emission factors used by the European Union and other territories, have become the default options globally for GHG emissions calculations.

It is expected that country-specific activities vary in intensity. This is seen in the CO2 footprints for kilos of beef in different countries with different methods of livestock production, but also in oilfields when comparing Canadian tar sands and Saudi conventional oil, for example. Differences in emissions factors will also exist within country causing further uncertainty.

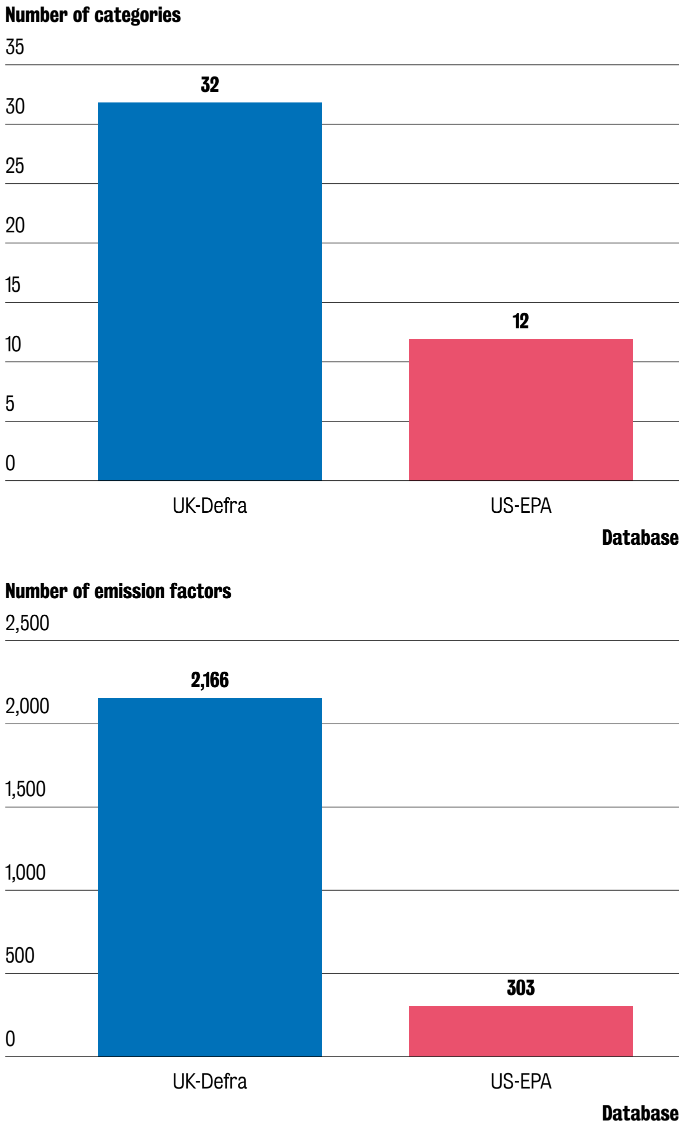
While differences across geographical databases is by no means the only source of potential gaming, they can be examined comprehensively using publicly available data. Other sources of variation such as the choice of calculation method (e.g., specific-based, average-based etc) are also likely to be material but require firm-specific input data to perform the comparison. We return to this issue in the next section.

The remainder of this section presents results from a novel mapping exercise, which provides a like-for-like comparison of the emissions factors provided in the UK-Defra and US-EPA datasets.

3.1. Dimensions of the Defra and EPA databases

To provide a clear overview of the datasets, it is important to understand the differences between the UK-Defra and US-EPA databases in terms of their categories and factors.[13] For the mapping of the datasets, we focus on the emission factors of Scopes 1, 2, and 3. The US-EPA database consists of twelve broad categories and encompasses a total of three hundred and three unique emission factors. On the other hand, the UK-Defra database offers a more detailed breakdown, with thirty-two categories and a significantly larger number of two thousand one hundred sixty-six unique emission factors.

Figure 3.1. Dimensions of UK-Defra and US-EPA emission factor datasets



Source: Authors' calculations

3.2. Mapping exercise

3.2.1. Methodology

To compare the emission factors provided in these datasets, we performed a line-by-line comparison of the average-based estimates they contain. We produce two conversion tables, each of which provides a uni-directional mapping from one database to the other. The full databases, alongside detailed documentation of the underlying assumptions, are available upon request. This exercise involved judgement in deciding which categories map to one another. To cross check our approach, three of the authors performed an independent mapping; cases of conflicting judgment were discussed in the wider group.[14]

The correspondence exercise is presented in a tabular structure, so that each row corresponds to a unique item in the source data which is matched to one or more items in the destination dataset. Matching these items is done primarily using the information provided in the datasets and the respective official methodology papers. Where the data follow a one-to-one matching relationship, i.e., where there is a direct match between single items in the two datasets, emissions in the source data are mapped directly to those in the destination dataset.

While this relationship is prevalent in some categories with more established definitions and disaggregation, such as fuels and materials, it is the exception rather than the norm. More commonly the mapping procedure follows a one-to-many relationship where a single item in the source data is matched to multiple items in the destination dataset. This is for example the case for many items relating to vehicles or transportation of goods, where discrepancies exist between the disaggregation of vehicle types. In these cases, our rule of thumb is to use the simple arithmetic average to calculate the CO_2e of the destination data. We concede that this aggregation does not always provide an ideal weighting scheme.

For illustrative purposes, consider the Scope 3 activity transportation of goods by aircraft. The UK-Defra database provides a disaggregate set of emission factors based on flight distance, whereas the US-EPA provides a single estimate reflecting the average such flight. In this instance, we map each UK-Defra factor to the average estimate provided in the US-EPA database. In the converse case, were we to map from the US-EPA database to UK-Defra, our procedure would be to map the single US-EPA factor to the arithmetic average of freight flights in the UK-Defra database. Note that the correspondence tables do not allow for a many-to-many matching relationship, as they are concerned with identifying the corresponding emissions of a specific item in the source data with those in the destination data.

We focus here on the mapping with UK-Defra as the base and match the components from the US-EPA to the components in UK-Defra. After performing the mapping exercise, we concentrate on the categories with emission factors that show different values and drop all the components that do not show a difference, or do not have a match. As highlighted

above UK-Defra overall is highly disaggregated and more nuanced in many categories than US-EPA.

There is also a large group of components in UK-Defra that do not have a direct match in US-EPA. For example, in the transport sector UK-Defra has emission factors for heavy goods vehicles, electric vehicles, and cars by size and market segment, which US-EPA does not. UK-Defra contains a category of hotel stay in various countries, which is not available for US-EPA. Where there is no meaningful match, we drop such components from our dataset. This leads us to a clean dataset of 636 unique emission factors from the previous 2166 emission factors.

This procedure leaves us with ten broad categories from the UK-Defra dataset namely – bioenergy, fuels, delivery vehicles, passenger vehicles, refrigerant and other from Scope 1; heat and steam, and electricity from Scope 2; and business travel – air, business travel – land, freighting goods, and managed assets – vehicles from Scope 3. We merged bioenergy and fuels for ease of reading, as many of the components are found in just one category of stationary combustion in the US-EPA. In summary, the analysis deploys a correspondence table of ten discrete categories of emission factors.

3.2.2. Results

Table 3.1 reports high-level summary statistics for the emissions factors contained in these ten databases. We provide a more granular comparison of these datasets in Figure 3.2.

We find that the emissions factors in the UK-Defra database are on average 10% lower than those in the US-EPA database. The UK-Defra emission factors are on average lower in seven of the ten categories. The categories with the largest divergences are: electricity, business travel by land and passenger vehicles, in each of which the US treatment is more stringent; and refrigerants and business travel by air, where the UK treatment is more stringent. We also find materially more variation in the emission factors contained in the UK database, reflecting its greater granularity compared to the coarser US database. In all but one category (passenger vehicles), there is greater dispersion of factors in the UK-Defra database. We explore these differences in the databases in more detail below.

Beginning with the categories in Scope 1, the emission factors for the 'bioenergy and fuels' category are 3% lower in the UK-Defra compared to the US-EPA. For 'delivery vehicles', UK-Defra has a large number of diverse emissions factors, whereas US-EPA is coarser with comparatively few emission factors covering a range of vehicles and fuel types. On average, emissions are 13% higher in the UK-Defra database for this category. Emissions from 'passenger vehicles' are on average 30% higher in the US-EPA, with the UK-Defra database again including a significantly larger number of distinct emissions factors. This is partly due to the greater disaggregation in the UK, where vehicles are categorized by size and market segmentation, allowing companies to report emissions for relatively environmentally friendly mini and super mini models. On the other hand, the US only provides one category for passenger cars with different emissions based on the year of manufacture. As for the 'refrigerant and other' category, CO2e emissions in the US-EPA are relatively sparse.

The two main categories in Scope 2, 'electricity' and 'heat and steam', have one and two activities, respectively. The large percentage differences of 24% and 54%, respectively, might be due to the limited availability of data in this sample.

Similar differences exist in Scope 3. 'Business travel – air' emissions are the highest, being 78% higher in the UK-Defra compared to the US-EPA, whereas for 'business travel – land', they are 33% higher in the US-EPA. In the 'business travel-air' panel, the distribution for the US-EPA is right-skewed with a high peak. On the other hand, for the 'business travel – land' panel, it is left-skewed with a lower peak. 'Freighting goods' show the lowest discrepancy between the two datasets, with emissions in UK-Defra being 3% lower compared to those in the US. Both datasets show a right-skewed distribution for freighting goods. Lastly, for 'managed assets – vehicles', the UK-Defra is 24% lower compared to the US-EPA, as there are some extreme values in the distribution of US-EPA.

In summary, we find significant differences between UK-Defra and US-EPA datasets of emission factors which preparers could use to maximise their outcomes. Differences become even larger when compared to reported GHG inventories taken from satellite measurements (Deng et al., 2022).

Table 3.1. Summary of results of market mapping (UK-Defra to US-EPA)

CO2e	Median			Standard deviation		
	UK Defra	US – EPA	% diff	UK Defra	US – EPA	% diff
Scope 1						
Bioenergy and fuels	0.24	0.25	-3%	0.11	0.07	43%
Delivery vehicles	0.81	0.72	13%	0.30	0.14	116%
Passenger vehicles	0.17	0.24	-30%	0.05	0.05	-6%
Refrigerant and other	2.55	0.58	343%	1.39	1.15	21%
Scope 2						
Heat and steam	0.17	0.23	-24%	–	–	–
Electricity	0.21	0.46	-54%	–	–	–
Scope 3						
Business travel – air	0.17	0.10	78%	0.14	0.01	1,050%
Business travel – land	0.14	0.22	-33%	0.07	0.05	33%
Freighting goods	0.29	0.30	-3%	0.53	0.39	35%
Managed assets – vehicles	0.23	0.30	-24%	0.37	0.34	10%
Total	**0.22**	**0.24**	**-10%**	**0.46**	**0.33**	**40%**

Figure 3.2. Comparison of the UK-Defra and US-EPA emission factors

Notes:

1. The horizontal axis represents the emission factors of the various activities, and the vertical axis shows the frequency of the observed emission factors.
2. For Scope 1, the units are: a) Bioenergy and fuels: kg/KWh kg/Litres, kg/tonnes, kg/KWh (gross CV); b) Delivery vehicles: kg/km; c) Passenger vehicles: kg/km; d) Refrigerant and other: tonnes (converted from original kg).
   For Scope 2, the units are: a) Electricity: kg/KWh; b) Heat and steam: kg/KWh.
   For Scope 3, the units are: a) Business travel – air: kg/passenger.km; b) Business travel – land: kg/km, kg/passenger.km; c) Freighting goods: kg/km, kg/tonne.km; d) Managed assets – vehicles: kg/km.

4. Pilot study

In this section, we examine the inherent uncertainty in the application of the GHG Protocol. As discussed in Section 2.2, for each scope, multiple accounting methods and emission conversion factors are permitted, though they have different hierarchy levels. Preparers may optimise their outcomes by applying the most beneficial methods or factors, not those producing the most accurate results. We report results from a pilot study which examines the quantitative materiality of the differences in databases and methods documented above.

To do this, we use proprietary data sourced from three anonymous Small and Medium-Sized Enterprises (SMEs) who provided us with information on their emissions-related activities (e.g., distance travelled in transporting goods, business miles by air travelled, etc).[15]

This exercise takes forward the analysis presented so far in two dimensions. First, given we have the true underlying activity data of these firms, we can compare the results by method employed (i.e., average-based vs spend-based, etc) in addition to doing so by geographical database. Second, we can weight any differences in method/database by the importance of that activity in a typical firm's business operations.

4.1. Description of the companies

Company 1 is a company which assembles rather than manufactures its products for onward sale so, it produces no Scope 1 emissions as part of the process. The sold products are recycled by the end users at the end of their life.

Company 2 manufactures refrigerator units; it purchases electrical items from suppliers and sells the manufactured units to downstream buyers. Its Scope 1 emissions are from transporting its products, and the activity data for GHG calculations are distances travelled by vehicles. The sold products are also recycled at the end of life.

Company 3 is a professional services company with shared offices. Given the nature of its business, this firm produces no Scope 1 emissions.

The Scope 2 emissions from all three companies results from their usage of purchased electricity. For Scope 3, their activity data inputs primarily include: purchased materials, disposal of sold products and waste generated in operations; employee commuting and business travel; electricity usage from home working; and cloud computing.

For Company 1 and Company 2, the data relate to the reporting window January 2021 to December 2021. For Company 3, the data cover reporting window September 2020 to August 2021. All inputs have been assured and are reported in line with the International Standard on Assurance Engagements (ISAE 3000).

4.2. Methods and data sources

For each company, we calculate its Scope 1–3 emissions (where applicable) using available databases and permitted methods. The databases include UK-Defra, US-EPA and EXIOBASE. The former two are described in Section 2. As the market-based emission factors are not available in both, we apply the factors from European Residual Mix (ERM) and Green-e Energy Residual Mix (Green-e) as the comparable ones in UK and US respectively. EXIOBASE is a global Environmentally Extended Input-Output (EEIO) database, used by the European Union and other jurisdictions.

The permitted methods include the specific-based and average-based methods for Scope 1, the market-based and location-based methods for Scope 2, and the average-based and spend-based methods for Scope 3 (see the discussion in Section 2).

In each case, we run the full set of input data through each method and database and report the results.[16] If anything, this underestimates the likely degree of dispersion we might expect to see in practice if preparers optimise their choice of methods and databases per activity. For instance, we know from the mapping exercise in Section 3 that the UK-Defra database has a more stringent treatment of business air travel than US-EPA, whereas the converse is typically the case for passenger vehicle travel.

4.3. Results

Table 4.1 presents the results of this exercise. The results for Scope 1 emissions are relatively consistent across methods and datasets. Recalling that only company 2 has Scope 1 emissions, we find that the average-based method using UK-Defra and US-EPA emission factors create similar results, with both close to the audited data provided by the company, calculated using the specific-based method.

Scope 2 results are also relatively consistent when obtained using the preferred market-based method (i.e., using emissions factors provided by power generating companies). But are materially inconsistent when obtained using the location-based method. The variations are driven by the low location-based emission factor provided by UK-Defra.

While Scope 3 results obtained using average-based methods are relatively consistent, we find extremely stark differences when employing the more commonly used spend-based method. The differences vis-a-vis the more accurate specific-based method are large in all cases, but especially so for the UK-Defra approach for Company 1 and Company 2. These differences warrant further investigation as we propose in Section 6.

Table 4.1. Results of the pilot study (ton C02e)

Company 1			
Scope 2 (ton C02e)	**UK**	**US**	
Location-Based	13.47	27.42	
Market-Based	24.18	29.21	
Scope 3 (ton C02e)	**UK**	**US**	**Exiobase**
Average-based	45,169.65	47,509.35	–
Spend-based	6,758.33	5,353.55	7,777.36
Company 2			
Scope 1 (ton C02e)	**UK**	**US**	**Reporting company**
Specific-based	–	–	22.04
Average-based	21.04	25.05	–
Scope 2 (ton C02e)	**UK**	**US**	
Location-Based	13.05	26.56	
Market-Based	23.41	28.29	
Scope 3 (ton C02e)	**UK**	**US**	**Exiobase**
Average-based	4,201.63	4,357.29	–
Spend-based	610.70	1,300.16	1,087.66
Company 3			
Scope 2 (ton C02e)	**UK**	**US**	
Location-Based	14.90	30.32	
Market-Based	26.73	32.30	
Scope 3 (ton C02e)	**UK**	**US**	**Exiobase**
Average-based	155.33	276.19	–
Spend-based	166.92	163.04	154.75

4.4. Materiality

How material are the differences in emission estimates documented above? The concept of 'materiality' assesses the risks to a company's ability to generate cash flow and profits in future (Lee, 2021). It is not concerned – contrary to what many assume – with the risks that the company poses to the environment or to society (Lepere, 2022). New EU rules introduced in 2018 make ESG reporting more meaningful by requiring large, listed companies and financial institutions to report on the external risks to their profits and cash flow, but also the ways in which their activities threaten environment and society. This is known in the jargon as 'double materiality'. In this analysis we adopt a double materiality approach and analyse both the environmental and financial materiality of our findings.

4.4.1. Environmental materiality

To examine environmental materiality, we consider the following thought-experiment: for a given set of company activity data, what is the largest and smallest feasible estimate of emissions obtainable using the calculation methods and databases permitted under the GHG Protocol?

We consider three scenarios. First, we posit that the three companies are UK-based, and we use UK-only emission factors to calculate the range of their emissions (shown in column 1 of the table). For example, for Company 1's Scope 2 emissions, the minimum is given by the location-based method (13.47) and the maximum by the market-based method (24.18). Second, we repeat the exercise assuming the companies are US-based. Third, we assume that the companies pick and choose methods and databases per activity category to maximise or minimise their reported emissions.

Table 4.2 presents the results of this exercise using the activity data from our pilot study. Each cell reports the maximum estimate of the company's emissions expressed as a multiple of the minimum.

Table 4.2. Environmental materiality of alternative calculation methods and databases

Optimised over	Company 1	Company 2	Company 3	Average
Methods available in UK databases	6.7x	6.6x	1.1x	4.8x
Methods available in US databases	8.8x	3.3x	1.6x	4.6x
All methods and databases by emissions category	11.3x	6.8x	1.9x	6.7x

The difference in emission estimates is stark. On average across the three companies, the maximum estimate is between 4.6 and 6.7 times the minimum. These effects are driven by Companies 1 and 2, whose Scope 3 emissions are mainly from purchased materials and goods transported where spend-based results are very different from those using the average-based method. If these firms are representative of the SME sector in the United Kingdom, our results suggest that this sector's actual emissions could be materially higher than the 146 million tonnes (CO2e) currently reported. Reaching the UK Government's ambition of halving SMEs emissions by 2030 may be more challenging than expected (DBEIS, 2021).[17]

4.4.2. Financial materiality

To examine the financial materiality of the variation in emissions reported above, we investigate how these alternative estimates might affect the cost of equity of a company. In doing so, we assume that the discrepancies highlighted for the SME firms in our pilot study are representative of the scale of discrepancy that might exist for the wider corporate sector. We use research findings by Bolton and Kacperczyk (2021) to produce these impact estimates. These authors reported cross-sectional regression results for listed US firms that showed larger Scope 1–3 emissions are associated with investors requiring a higher return on equity.

To give a sense of the scale of these effects, we conservatively focus on the impact of moving from UK-Defra to US-EPA estimated emission factors. We find an increase in the cost of equity for Companies 1–3 of our pilot study of 10 basis points, 8 basis points, and 120 basis points respectively in moving from UK to US factors.

If we take these firms to be representative of the wider corporate sector, this translates into a cost of equity increase of 46 basis points for the sector as a whole,[18] and effect that would reduce equity valuations by approximately 1.9%.[19] To continue this simple thought experiment, in the extreme assumption where *all* US companies use UK-Defra rather than the US-EPA database to calculate their emissions, the realisation of this gaming would lead to a $650bn reduction in market capitalisation.

5. What incentives does the Protocol create?

Reporting companies can misstate their GHG emissions intentionally or unintentionally. As per the International Standard on Assurance Engagements (ISAE) (2020), misstatements in GHG reporting occur due to the difference between the reported information of the subject matter and the actual measurements or evaluation of the underlying subject matter in accordance with the specified criteria, and they can be unintentional or intentional. Misstatements are considered material if they affect the decisions made by users of the GHG information (UNFCCC, 2011). In practice, preparers can game emissions by intentionally overestimating or underestimating CO2e emissions through the choices of data sources of emission conversion factors and methods for GHG inventory. This section analyses the incentives for preparers to do so.

5.1. Rating shopping

One concern the Protocol gives rise to is the potential for firms to engage in a practice akin to 'rating shopping'. Rating shopping refers to a situation where a bond issuer engages with several credit rating agencies with the intention of choosing only the most favourable assessment of the security. This practice is believed to have contributed to the inflation of ratings for structured finance products such as mortgage-backed securities prior to the 2007–8 financial crisis, which in turn undermined financial stability in that period (Benmelech and Dlugosz, 2010).[20]

Specific characteristics of the market for bond credit ratings are believed to have contributed to this behaviour. First, the market operates on an 'issuer pays' model, under which bond issuers pay rating agencies directly for the ratings provided. This model has been criticised by some because it generates potential conflicts of interest in that the issuer being evaluated is also paying for the service. While it had been contended that the oligopolistic structure of the industry and the rents this generated would guard against this risk, subsequent research has argued that if reputational concerns are not strong enough to discipline rating agencies, the issuer-pays model can result in inflated ratings (Bolton et al., 2012). Second, the market convention was that issuers pay for a rating only when it asks for that rating to become public and are free to solicit ratings from other agencies. Third, the complexity of the structured finance products being rated (Skreta and Veldkamp, 2009) and the lack of public information on the securities (Benmelech, 2010) generated sufficient dispersion in ratings to create incentives to shop – incentives that were not present for plain-vanilla corporate and municipal bonds.

It is striking that many of these characteristics are also potentially present in the market for emissions reporting. Companies pay preparers directly for the emission estimates they produce; while payment is made regardless of whether the emissions are disclosed, the cost of this service is small relative to the potential financial impact on the company of achieving a more favourable estimate of its emissions. The market is competitive, with hundreds of preparers competing for business; this, combined with the fact that preparers are relative newcomers who have not yet built a reputation for credible estimates, suggests that a desire to protect reputation and future rents is unlikely to provide a sufficient bulwark to ensure emissions accuracy. Finally, as we have seen, the calculation of emissions for even a relatively small company is a complex process involving non-public information, conditions which are likely to lead to dispersion in emission estimates and shopping incentives.

A further consideration relates to the interaction between ratings/emissions estimates and financial regulation. Credit ratings were extensively used prior to the global financial crisis in determining minimum capital requirements for banks and insurance companies and ratings-based mandates for pension funds. This created a natural clientele for highly rated structured finance securities, contributing further to the incentives of rating agencies to produce favourable ratings.

Again, there is an analogy with estimates of GHG emissions. Carbon pricing systems, such as the EU's Emissions Trading System (ETS), rely on the GHG Protocol and are designed to provide financial incentives for emission reduction, thus encouraging technological innovation and transition towards a low-carbon economy. As carbon prices rise in future, this will create larger direct financial incentives to reduce reported emissions, which in turn we might expect will incentivise preparers to select the most favourable methods and data sources, underestimating companies' actual emissions. Moreover, as we discussed in the previous section, there is some evidence that companies with high emission profiles already face higher costs of capital (Bolton and Kacperczyk, 2021), potentially bringing forward the incentives of companies to minimise their reported emissions.

Second, extensive studies have shown that companies with observed higher reported GHG emissions are linked with higher costs of equity. This can be attributed to the growing concern among investors regarding climate risk and their commitment to supporting the transition to a low-carbon economy. Further evidence suggests that investors are less responsive to the negative performance of ESG or environmentally focused funds (Capotă et al., 2022), which encourages fund managers to invest in companies with low emission profiles. The second channel also incentivizes preparers to under-report their GHG emissions, which could provide biased information for investors and potentially affect investor decision-making.

5.2. Inflating emissions

There are incentives to inflate baseline emissions numbers or select an inappropriately high baseline (Victor et al., 1998). Inappropriate baselines of global emissions create larger markets for carbon offsets and may incentivise unwarranted investment (Fischer, 2005). A distinct potential concern arises in the circumstances where preparers provide bundled services, which combine the calculation of a company's gross emissions with the opportunity to purchase carbon offsets. A typical pricing structure for such a bundle would provide the emissions calculation at a small cost relative to the margins made by the preparer on selling the corresponding offsets. Setting aside the widespread concerns about the effectiveness and legitimacy of the carbon offsets market, this contract structure creates incentives for an upward bias in preparers emissions calculations.

We discuss policy options for addressing these concerns in the next section.

6. Conclusion and policy recommendations

In this paper, we have documented the framework for calculating greenhouse gas emissions under the GHG Protocol. This framework is complex: it involves the collection and management of large datasets on companies' activities, and both scientific and estimation uncertainty in translating such activities into emissions estimates. Moreover, there are substantial degrees of freedom created by the existence of multiple calculation methods and emission factor databases, which deliver markedly deliver emissions estimates for the same underlying activity data inputs. Preparers are required to exercise judgement in selecting the appropriate approach to employ. This framework, we argue, creates distorted incentives for preparers and is unlikely to produce accurate estimates of companies' true emissions in a durable way.

To conclude the paper, we offer a set of five policy recommendations for those charged with policymaking in this area to consider. These recommendations echo calls for reform and are aimed at making the calculation of GHG emissions and their reporting robust (e.g., UN, 2023; HM Treasury, 2023).

Recommendation 1: Regulate preparers of GHG emissions calculations and require external audit.

In response to the 2008 financial crisis, new rules were introduced which established a regulatory framework and oversight regime for rating agencies. In the EU, for example, rating agencies were required to be registered and supervised by national competent authorities. They were also required to avoid conflicts of interest and have sound and transparent rating methodologies.

We think there is merit to considering a similar approach in this case. The preparation and disclosure of carbon emissions remains an unregulated industry. Significant numbers of established players and new start-ups have emerged in recent years providing carbon calculation services for companies, financial institutions, and organisations in the private and public sectors (JRC, 2022). Policymakers should consider introducing a requirement that preparers be registered and supervised by competent authorities. This, we argue, would be a critical step in the process of meaningfully integrating these data with financial accounts. While such regulation typically creates barriers to entry and reduces competition, it also has the effect of incentivising responsible behaviour from established market players who are less likely to risk sanction and future revenues.

As a second line of defence against the risk of emission gaming we recommend there should be a requirement that GHG emissions prepared by carbon calculators be audited by an external Chartered Accountant (Certified Public Accountant) or equivalent authorised professional. In addition, GHG calculations and reports should be required to pass the appropriate International Standard on Assurance Engagements or attestation standards.[21] The requirement to audit CO2e emissions calculations is intended to mitigate the potential for emissions gaming by introducing the concept of professional scepticism to GHG emission preparation and reporting.[22]

There is at present a skills gap in the auditing and accounting professions in calculating, auditing, and reporting GHG emissions. Nevertheless, the profession, with its ethical duty to act in the public interest, is best placed to undertake this work, and led by the ISSB, it is rapidly building capacity.[23]

Recommendation 2: Require reporting entities to disclose the proportion of all scopes that are covered and assured (ISAE 3000).

Building on recommendation 1, we see significant merit in requiring that companies, as part of their emissions reporting, disclose the proportion of their emissions that has been covered and assured in line with ISAE 3000 or its equivalent. We think it valuable to disclose this information both at the individual scope level and at the aggregate level. For example, it might be that 100% of Scope 1 (direct emissions through burning fuel and using refrigerants) is assured, but that only 28% of Scope 2 (indirect emissions via energy consumption) and only 5% of Scope 3 (emissions in the supply chain) can be assured. For a company where the majority of its emissions are Scope 3, our suggested metric would be closer to 5% than 100%. The benefits of such a requirement primarily relate to the additional information it would provide to prospective and existing investors as to the scope and quality of the reporting entity's emissions disclosure. But we think the existence of such a requirement would also be likely to act as a mitigation to market incentives and a deterrent to emissions gaming.

Recommendation 3: Require reporting entities to disclose the methods and datasets used in their emissions calculations up front in their accounts and to restate historical data to aid comparison.

We recommend that reporting firms be mandated to disclose the judgments, methods, datasets and emission factors used in the calculations. Unlike in financial reporting, we argue that this information should be provided up-front and not be relegated to the notes to the accounts – this will help to educate users and draw attention to inherent estimation uncertainty in greenhouse gas reporting.

As scientific knowledge advances, we are likely to benefit from improved estimates of the greenhouse gas emissions associated with activities or the GWP (again, global warming potential) of different gases. We recommend that preparers should not only always use state-of-the-art GWPs (as the GHG Protocol recommends) but they should also disclose the period assumed e.g., a 20 year or 100-year GWP. This will help users assess this aspect of uncertainty of reported emissions and help to mitigate any potential emissions gaming using GWP updates.

We expect updated GWPs and assumptions will make structural breaks in companies' reported emissions a common occurrence. The prospect of having to report a year-on-year step increase in reported emissions despite transition plans being executed faithfully may not sit well in Board rooms. To mitigate such concerns and the associated incentives to present ever-lower emissions relative to baseline, which may bear a decreasing resemblance to reality, reporting entities should be mandated to restate their historical emissions data in such cases to aid comparison.[24] We suggest a five-year period in which restatements may be made – consistent with the restatement window for financial data in company reporting.

This recommendation targets the inherent uncertainty in the application of the GHG protocol, a necessary condition for emissions gaming. The requirements to disclose methods, datasets and judgements used in GHG calculations, to include such information up-front in the accounts, and to restate historical data when scientific advances are made would significantly improve the credibility of these data and provide a critical evidence base for future research.

Recommendation 4: Require reporting entities to calculate and disclose emissions using datasets that are representative of where the emissions producing activity takes place. Reporting entities should also report against different emission factor datasets, including both local and global.

The three global datasets of emissions factors provided by UK-Defra, US-EPA and EEIO appear to be mainstream and are the default choice for multinational companies and for companies operating in other jurisdictions (ghgprotocol.org). Where local datasets are available, the GHG Protocol permits their use.

To reduce uncertainty in the application of the protocol, we recommend that the GHG Protocol be tightened up in two respects with regards to firms' choice of emission factor datasets. First, where feasible, firms should be mandated to use datasets produced by their local jurisdictions as these will be most representative of their actual level of emissions. Where these are not available, firms should use a dataset that is likely to be most representative of the emission factors for own country. Where a firm is operating in multiple countries, they should choose emission factor databases corresponding to where the emissions producing activity takes place. Second, we recommend that firms should calculate and disclose their GHG emissions using both local and global datasets in their annual company reports. Such disclosures would help to assuage concerns of cherry-picking databases with lower emission standards, while also helping to identify and narrow important differences in the emission factors provided.

Recommendation 5: National agencies should investigate categories of emissions factors with large variances across datasets.

The evidence we presented in Sections 3 and 4 of this paper highlighted material differences in emission factors between UK-Defra, US-EPA and EEIO databases for some categories of activity. Our final recommendation is that national agencies responsible for the maintenance of these databases should investigate categories with large deviations geographically.

While some such differences are appropriate and will reflect reality (e.g., the fuel efficiency of passenger cars will differ by jurisdiction), others appear harder to rationalise. For instance, our analysis uncovered striking differences in the emissions factors for certain categories of Scope 1 emissions, with the UK-Defra emission factors greater than the US-EPA equivalents by a factor of 1000% to more than 80,000% (see Section 3). We also found material differences for certain Scope 2 and 3 emission factors.

We encourage national agencies to investigate these cases and seek to align estimates with each other where appropriate,[25] and in all cases with the latest scientific knowledge. Such 'bottom-up' estimates of GHG emissions can also be compared to 'top-down' estimates from satellite measurement, in the so-called inversion method. Inverse estimates have recorded significant discrepancies with corresponding national reports and can provide a critical source of triangulation (Deng et al., 2022).

6.1. Summary of policy recommendations

We summarise our recommendations in Table 6.1. Taken together, these would help to reduce uncertainty inherent in the GHG Protocol and mitigate incentives for emissions gaming. These recommendations are aimed at acting in the public interest. They create an evidence base, in the public domain, that provides data on reporting entities of varying types and sizes in the private and public sectors at local, national, and regional levels.[26]

The recommendations work to mainstream knowledge and understanding among preparers, reporters, and users of GHG emissions data. The public sharing of methods and calculations provides evidence for greater standardisation, much demanded by all parties (Faber, 2022). For example, there has been calls for standardised lifecycle emissions accounting and inventories for certain components that are widespread in value chains such as steel, cement, and electrical components (Devlin and Markkanen, 2023).[27]

Finally, taken together, these recommendations create a dynamic bank of evidence to guide learning; a feed-back loop that helps to narrow estimation of GHG emissions over time in the common interest. We hope this paper motivates further research into emissions calculations, baselining and reporting with implications for decarbonisation targets, carbon markets, and transition risks.

We hope this paper motivates further research into emissions calculations, baselining and reporting with implications for decarbonisation targets, carbon markets, and transition risks

Table 6.1. Summary of policy implications

No	Recommendation	Primary contribution
1	Regulate preparers of GHG emissions calculations and require external audit.	Public interest; consistency with financial reporting.
2	Introduce a new metric that requires reporting entities to disclose the proportion of all scopes that are covered and assured (ISAE 3000).	Increased transparency and greater standardisation.
3	Require reporting entities to disclose up-front methods and datasets used in calculations and to restate historical data to aid comparison.	User awareness of variation and knowledge of source.
4	Require reporting entities to calculate and disclose emissions using datasets that are representative of where the emissions producing activity takes place. Reporting entities should also report against different emission factor datasets, including both local and global.	Dynamic evidence bases for future research.
5	National agencies should investigate categories of emissions factors with large variances across datasets.	Narrow variation in datasets over time.

Annex 1. Literature review

In this section, we will review existing studies that contribute to understanding the uncertain nature of GHG calculations. This literature review is structured as follows: to begin with, we will review the methods recommended by GHG Protocol to quantify the uncertainty in the emission value of a single activity that is a source of emissions. Following this, we will focus on how existing studies quantify uncertainties in parameters (i.e., activity data and emission factors) and GHG values for a given activity. Then, we will mention research that improves existing methods for uncertainty assessment. In the final step, we will discuss the gaps in prior studies.

Methods of combining uncertainties of parameters

GHG Protocol (2003) recommends two assessment tools for quantifying statistical uncertainty in GHG inventory preparation: the error propagation method (the Gaussian method) and the Monte-Carlo method. The major difference between these two methods is that the Gaussian method assumes the normally distributed errors in each parameter (i.e., activity data and emission factors).

Aggregating uncertainties through the error propagation method involves the following steps. To begin with, this method assumes that the measurement data follows a normal distribution (student t-distribution), and the uncertainty range for any given parameter is denoted as a 95% confidence interval. Next, the preparer should combine uncertainty for single activity's emissions by multiplying the uncertainties of activity data and the relevant emission factor:

Multiplying uncertainties: where:
$(A \pm a\%) \times (B \pm b\%) = C \pm c\%$
with $c = \sqrt{a^2 + b^2}$

where (A ± a%) represents the uncertainty range of the emission factor and (B ± b%) represents that of activity data. (C ± c%) represents the uncertainty in a single activity's emissions. Then, to aggregate the parameter uncertainties across single activities, one can simply add the uncertainties:

Adding uncertainties: where:
$(C \pm c\%) \times (D \pm d\%) = E \pm e\%$

$$e = \frac{\sqrt{(C \times c)^2 + (D \times d)^2}}{E}$$

where (D ± d%) represents the uncertainty range of another single activity.

Although the Monte-Carlo method relaxes the assumption of normally distributed parameters, it still requires that the probability distributions for each parameter to be specified. The uncertainty for each parameter is expressed as a probability density function, derived from various methods including statistical data analysis and expert judgment. The essence of this method is randomly selecting values of emission factor and activity data (for a single activity) from their respective individual probability distributions and computing the corresponding emission values through multiplication. This procedure is reiterated many times. The outcomes are building up a probability density function for the emission value of this single activity (Hiraishi et al., 2006).

Quantifying uncertainties associated with parameters

Two parameters are necessary for GHG calculations: activity data and emission conversion factors. Activity data are usually collected and published by national statistical agencies and reporting companies, and they have relatively low correlation and uncertainties when compared with emission factors. Emission factors can be generated from direct measurement. For example, if the periodic emission measurements are available at a site, which can be linked to the representative activity data, then it is possible to calculate a site-specific (periodic) emission factor (Hiraishi et al., 2006). The factors can also be collected indirectly from published sources, which include the published databases (e.g., IPCC Emissions Factor Database), government statistics (e.g., Defra and EPA), literature studies, and industry associations (WRI and WBCSD, 2013).

Corresponding to the sources of parameters, uncertainty estimates are based on measurement data, default uncertainties recommended by published sources, such as IPCC (Hiraishi et al., 2006), and literature studies, as well as expert judgment when empirical data is not available (Rypdal and Winiwarter, 2001). Uncertainty of a given parameter is expressed as a confidence interval or probability density distribution, depending on whether the error propagation method or the Monte-Carlo method is employed. If the measurement data is available and the sample size is large enough, the variations in data can be used as the estimated random uncertainty (Monni et al., 2007). For example, given the periodic emission measurements and the relevant activity data, one can determine a site-specific emission factor for each period (Hiraishi et al., 2006), as well as the uncertainty estimated based on the variations among different measurement periods. In practice, the uncertainty in emission factors can also be derived from the variations within individual measurement series and the information on measurement instruments (Monni, Syri and Savolainen, 2004). The emission factors from published sources or literature studies are usually provided with recommended uncertainties. In this part, we review existing studies that quantify the uncertainties associated with parameters and the resulting GHG inventories.

Some studies analyse uncertainties at the national level. For example, Winiwarter and Rypdal (2001) investigate the uncertainty associated with Austrian GHG inventories. The uncertainties in parameters are generated from the expert interviews, based on which, the uncertainties associated with sectors are combined through the Monte-Carlo method. The resulting uncertainties in national GHG inventories are 10.5% and 12% in 1990 and 1997 respectively. Monni, Syri and Savolainen (2004) also investigate the uncertainties at the national level for Finnish GHG inventories. The estimated uncertainties for the parameters are derived from multiple sources including measurement data, literature studies, expert judgment, and recommendations from IPCC. Uncertainties of parameters are combined across the input parameters and across sectors through the Monte-Carlo method. They found that while CO_2 is the primary greenhouse gas, other gases exhibit higher uncertainties. The overall uncertainty in the 2001 emissions was calculated to be between -5% and +6%, which indicates that Finnish emissions were between 75 and 84 Mt CO_2e in that year.

Another strand of research focuses on regional GHG inventories and uncertainties associated with the spatial distribution of emissions. Bun et al. (2010) investigated the uncertainties in GHG inventories for the energy sector in the Lviv region of Ukraine through spatial analysis. This methodology allows them to investigate emissions for each grid cell within the region, which provides information to estimate the uncertainties in parameters (i.e., activity data and emission factors). Given the mean values and probability density functions for the spatially distributed activity data and emission factors, Bun et al. (2010) combine the uncertainties in GHG inventories of separate grids through the Monte-Carlo method. The resulting uncertainty in the regional GHG inventories is approximately ±7.5. The approach based on spatial analysis is better at accounting for the variations in economic activities and unique features of fuel management for different grid cells. Bun et al. (2010) also applied an alternative approach that does not rely on spatially distributed data, and the resulting uncertainty is ±9.4%. The results highlight that spatial analysis can help to reduce uncertainties in GHG inventory.

Existing studies also include those examining uncertainties in life cycle emissions. For example, Venkatesh et al. (2011) examines the uncertainty of life cycle GHG emissions related to petroleum-based fuels consumed in the US. The life cycle begins with extraction and ends with combustion. They use a process-based approach and statistical modelling methods to estimate the uncertainty and find that the uncertainty range in GHG emissions from gasoline is 13%, which is greater than the typical 10% minimum emissions reduction targets established by low-carbon fuel policies.

Another strand of papers focuses on the uncertainty associated with databases applied in modelling and policymaking. Solazzo et al. (2020) determines the uncertainty in the Emissions Database for Global Atmospheric Research (EDGAR), which estimates the global human-induced emissions of CO_2, CH_4 and N_2O. The uncertainties in activity data and emission conversion factors are from IPCC and they are combined through the error propagation method. Solazzo et al. (2020) find that the anthropogenic emissions estimated by EDGAR for the three gases for 2015 are within an accuracy range of -15% to +20%.

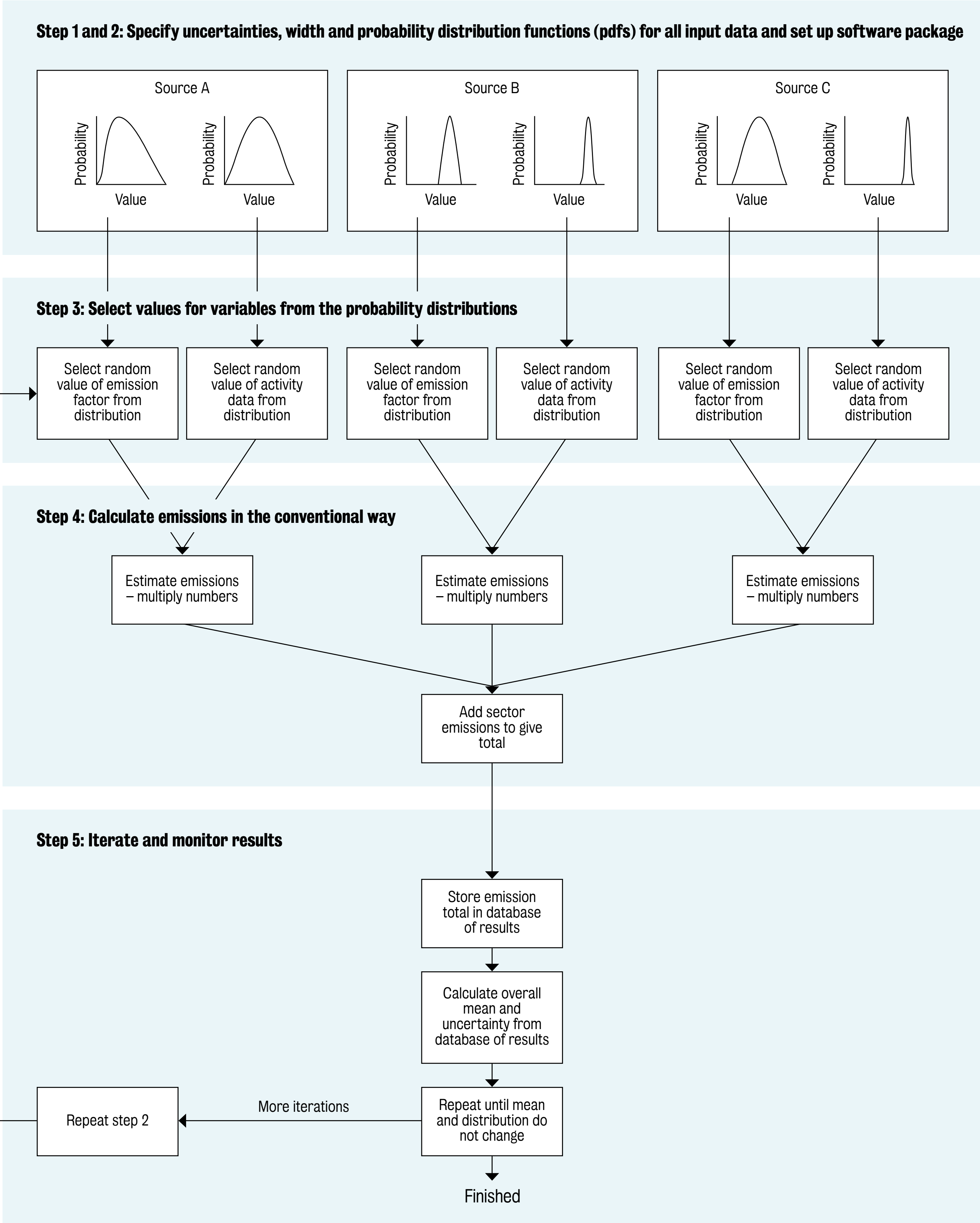
Improving the methods of quantifying uncertainties

Another strand of research focuses on the methods to improve uncertainty assessment for GHG accounting. For example, Perkins and Suh (2019) investigate how the hybrid method in life cycle analysis (LCA), which combines input-output and process data, affects the uncertainty of GHG emissions. According to their findings, implementing the hybrid approach enhances the accuracy of LCA outcomes while maintaining their precision. They also suggest that prioritizing the collection of supplier-specific data can also enhance precision without incurring excessive costs. Marujo et al. (2022) propose a method for estimating the mean and variance of total CO_2 emissions from multiple sources of a company, which considers the correlations among emissions from different sources and represents an improvement over existing methods that assume independence.

Implications and gaps

Although extensive studies contribute to understanding the uncertain nature of GHG calculations, several gaps remain. First, while most research focuses on the uncertainties in GHG inventories at the regional, national or sectoral levels, the uncertainties at the company level are seldom analyzed. Second, current research focuses on quantifying statistical uncertainties of parameters (i.e., activity data and emission factors). Statistical uncertainties are results of natural variations in the preparation of GHG inventory, such as human errors in the measurement process, which are unintentional. However, preparers can create uncertainties intentionally. For example, preparers can choose the emission factors that they can benefit from when calculating GHG emissions, which leads to rating shopping and inflating emissions. Third, few studies analyze how uncertainties, especially those created intentionally (the game-ability in GHG reporting), affect the financial performance of reporting companies or organizations, as well as the achievement of carbon neutrality targets set by the government.

Figure 1. Illustration of the Monte-Carlo method



Annex 2. Specific/average/spend-based methods for Scopes 1 & 3

To aim communication for non-experts, we have created a high-level taxonomy of the detailed methods for Scopes 1 and 3 recommended by the GHG Protocol. We categorize them into three types: specific-based, average-based and spend-based.

For Scopes 1 and 3, one can apply the specific- and average-based methods. The major difference between them is the emission conversion factor employed in calculations. In the context of Scope 1, the specific-based method multiplies a reporting company's activity data with the specific emission conversion factors estimated and reported by this company. In the context of Scope 3, the calculations using the specific-based method apply the specific factors estimated and reported by the reporting company's value chain partners, which can include transportation carriers, suppliers and others on the value chain. In this report, we classify the emission factors developed by the reporting company (for Scope 1) and its value chain (for Scope 3) as primary data.

For both Scopes 1 and 3, the average-based method multiplies the activity data of this company with the secondary emission factors (e.g., industry average emissions per unit of activity data) that are from published sources, which include the open databases (e.g., IPCC Emissions Factor Database), government statistics (e.g., Defra and EPA), literature studies, and industry associations. The secondary emission factors for the average-based method exclude EEIO factors.

For Scope 3, we create a correspondence table to map the detailed methods as per category recommended by the GHG Protocol (WRI and WBCSD, 2013) into the three distinct methods we have developed for the uncertainty matrix. The mapping strategy is based on the data sources of emission factors (i.e., primary data or secondary emission factors). If a method uses primary data in calculations, we classify it as specific-based. On the other hand, if a method uses secondary emission factors (excluding EEIO factors), then we classify it as average-based. The spend-based method can be applied for some categories of Scope 3, and it employs the EEIO factors in calculations.

Figure 2. Mapping methods recommended by GHG Protocol to specific/average/spend-based methods

Scope 3 category	Methods recommended by ghg protocol	Specific/average/ spend-based methods
1 Purchased goods and services	Supplier-specific method	Specific-based
	Hybrid method	-
	Average-data method	Average-based
	Spend-based method	Spend-based
2 Capital goods	Supplier-specific method	Specific-based
	Hybrid method	-
	Average-data method	Average-based
	Spend-based method	Spend-based
3 Fuel- and energy-related activities not included in Scope 1 or Scope 2	Supplier-specific method	Specific-based
	Average-data method	Average-based
4 Upstream transportation and distribution (transportation)	Fuel-based method	Specific-based or average-based
	Distance-based method	Specific-based or average-based
	Spend-based	Spend-based
Upstream transportation and distribution (distribution)	Site-specific method	Specific-based or average-based
	Average-data method	Specific-based or average-based
5 Waste generated in operations	Supplier-specific method	Specific-based
	Waste-type-specific method	Average-based
	Average-data method	Average-based
6 Business travel	Fuel-based method	Specific-based or average-based
	Distance-based method	Specific-based or average-based
	Spend-based	Spend-based
7 Employee commuting	Fuel-based method	Specific-based or average-based
	Distance-based method	Specific-based or average-based
	Average-data method	Specific-based or average-based
8 Upstream leased assets	Asset-specific method	Specific-based or average-based
	Lessor-specific method	Specific-based or average-based
	Average-data method	Average-based
9 Downstream transportation and distribution (transportation)	Fuel-based method	Specific-based or average-based
	Distance-based method	Specific-based or average-based
	Spend-based	Spend-based
Downstream transportation and distribution (distribution)	Site-specific method	Specific-based or average-based
	Average-data method	Specific-based or average-based
10 Processing of sold products	Site-specific method	Specific-based or average-based
	Average-data method	Specific-based or average-based
11 Use of sold products	Calculation methods for direct use-phase emissions and indirect use-phase emissions	Specific-based or average-based
12 End-of-life treatment of sold products	Supplier-specific method	Specific-based
	Waste-type-specific method	Average-based
	Average-data method	Average-based
13 Downstream leased assets	Asset-specific method	Specific-based or average-based
	Lessor-specific method	Specific-based or average-based
	Average-data method	Average-based
14 Franchises	Franchise-specific method	Specific-based or average-based
	Average-data method	Average-based
15 Investments	Investment-specific method	Specific-based
	Average-data method	Spend-based

Annex 3. Country specific datasets and methodologies

Countries that are Parties to the United Nations Framework Convention on Climate Change (UNFCCC) submit National Inventory Reports (NIRs). The NIRs are reports containing estimates with detailed descriptive and numerical information about a country's GHG emissions and removals. The NIRs contain:

- **Inventory Methodology:** the methodologies used to estimate GHG emissions and removals within the country
- **Sectoral Coverage:** sector-wise breakdown of emissions, including energy, industry, agriculture, waste management, and land use
- **Emission Sources and Sinks:** sources of GHG emissions and sinks (removals) within the country
- **Data and Assumptions:** data sets, assumptions, and calculations used to estimate emissions and removals

The UNFCCC guidelines provide flexibility for countries to choose either average based or spend based methodologies and each methodology is described in each country report. For example, the UK provides the Defra datasets (for average-based), the US provides EPA (for average-based) and US-EEIO datasets (for spend-based).

Figure 3. Datasets for emission factors

Source: United Nations – United Nations Framework Convention on Climate Change[28]

ID	Country	National Inventory Report	Latest submitted NIR
1	Australia	https://unfccc.int/documents/627765	13 Apr 2023
2	Austria	https://unfccc.int/documents/627757	13 Apr 2023
3	Belgium	https://unfccc.int/documents/627808	14 Apr 2023
4	Bulgaria	https://unfccc.int/documents/627709	12 Apr 2023
5	Canada	https://unfccc.int/documents/627833	14 Apr 2023
6	Croatia	https://unfccc.int/documents/627738	13 Apr 2023
7	Cyprus	https://unfccc.int/documents/627714	10 May 2023
8	Czechia	https://unfccc.int/documents/627756	13 Apr 2023
9	Denmark	https://unfccc.int/documents/627788	14 Apr 2023
10	Estonia	https://unfccc.int/documents/627754	13 Apr 2023
11	European Union	https://unfccc.int/documents/627851	15 Apr 2023
12	Finland	https://unfccc.int/documents/627718	12 Apr 2023
13	France	https://unfccc.int/documents/627737	13 Apr 2023
14	Germany	https://unfccc.int/documents/627785	14 Apr 2023
15	Greece	https://unfccc.int/documents/627770	13 Apr 2023
16	Hungary	https://unfccc.int/documents/627849	15 Apr 2023
17	Iceland	https://unfccc.int/documents/627842	15 Apr 2023
18	Ireland	https://unfccc.int/documents/627850	17 Apr 2023
19	Italy	https://unfccc.int/documents/627845	14 Apr 2023
20	Japan	https://unfccc.int/documents/627900	21 Apr 2023
21	Kazakhstan	https://unfccc.int/documents/627844	15 Apr 2023
22	Latvia	https://unfccc.int/documents/627724	12 Apr 2023
23	Liechtenstein	https://unfccc.int/documents/627729	13 Apr 2023
24	Lithuania	https://unfccc.int/documents/627669	07 Apr 2023
25	Luxembourg	https://unfccc.int/documents/627747	13 Apr 2023
26	Malta	https://unfccc.int/documents/627693	12 Apr 2023
27	Monaco	https://unfccc.int/documents/627688	11 Apr 2023
28	Netherlands	https://unfccc.int/documents/627759	13 Apr 2023
29	New Zealand	https://unfccc.int/documents/627783	13 Apr 2023
30	Norway	https://unfccc.int/documents/627398	15 Mar 2023
31	Poland	https://unfccc.int/documents/627153	28 Mar 2023
32	Portugal	https://unfccc.int/documents/627602	03 Apr 2023
33	Romania	https://unfccc.int/documents/627662	06 Apr 2023
34	Russian Federation	https://unfccc.int/documents/627871	18 Apr 2023
35	Slovakia	https://unfccc.int/documents/627782	13 Apr 2023
36	Slovenia	https://unfccc.int/documents/627824	14 Apr 2023
37	Spain	https://unfccc.int/documents/627815	14 Apr 2023
38	Sweden	https://unfccc.int/documents/627663	06 Apr 2023
39	Switzerland	https://unfccc.int/documents/627731	13 Apr 2023
40	Turkey	https://unfccc.int/documents/627786	14 Apr 2023
41	Ukraine	https://unfccc.int/documents/628276	18 May 2023
42	United Kingdom	https://unfccc.int/documents/627789	14 Apr 2023
43	United States	https://unfccc.int/documents/627784	14 Apr 2023

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Endnotes

1 Global dataset of emission factors should not be confused with National Emission Inventories (NEIs). NEIs contain detailed descriptive and numerical information and the Common Reporting Format (CRF) tables contain all greenhouse gas (GHG) emissions and removals, implied emission factors and activity data.

2 See Annex 3.

3 This difference seems relatively small compared to differences between reported inventories and satellite measurements (Deng et al., 2022).

4 Indeed, the UK government specifically calls for the use of the Defra emission factors to be used more widely: 'These emission conversion factors are for use by UK and international organisations to report on 2022 greenhouse gas emissions (Department for Energy Security and Net Zero, 2022)'.

5 We are in the Anthropocene; an era in which human activity is driving changes in climate, biodiversity and earth systems at a planetary scale (Steffan et al., 2011). Specifically, the IPCC (2023) has a high degree of confidence that human activity is unequivocally the principal cause of global warming. Regulators and standard setters are committed to deploying a new 'global baseline' of carbon accounting and sustainability disclosure standards being developed by the International Financial Reporting Standards (IFRS) Board. The IFRS introduced the International Sustainability Standards Board (ISSB) to bring the same discipline, rigour and professionalism of financial reporting to carbon and non-financial accounting. The first ISSB standard including standards for carbon accounting are being released in June 2023.

6 The rule documentation used to construct the correspondence table between UK-Defra and US-EPA emission factor datasets is available upon request.

7 A detailed description of the taxonomy is provided in Annex 2.

8 The spend-based method cannot be applied for some categories of Scope 3 emissions, such as employee computing and waste generated from operations.

9 EEIO models are used to calculate greenhouse gas (GHG) emissions produced by a particular sector or product category, considering the entire production process and supply chain. These models allocate national GHG emissions to different finished products or specific industries based on economic transactions between sectors (WRI and WBCSD, 2011).

10 The spend-based method is also used by financial institutions to account for the emissions they are 'financing' using what is called an attribution factor. This factor deploys the value of the financed company which is based on enterprise value including cash (EVIC), which, in the case of listed companies, fluctuates with the equity price (PCAF, 2022). The (re)calculation of EVIC between two reporting periods adds further uncertainty to reported GHG emissions.

11 For instance, according to the Intergovernmental Panel on Climate Change Assessment Report 5 (IPCC AR 5), one kilogram of nitrous oxide emitted equates to 265 kilograms of CO2e (IPCC, 2014). Nitrous Oxide therefore has a GWP of 265.

12 The term 'regulatory arbitrage' captures a wide range of phenomena, including cases where financial firms optimise the cross-jurisdictional distribution of their activities or asset holdings to exploit differences in regulatory treatment. It also captures cases where financial firms respond to the incentives created by some regulations, eg where there is little differentiation of rules by risk, the incentives are to take more risk. Finally, it covers situations where financial firms exploit the complexity of the regulatory framework to make assumptions that minimise their regulatory burden.

13 Readers may also wish to compare UK Defra and US-EPA against International Energy Agency's (IEA) emissions factors, which preparers are paying to use in many countries. https://www.iea.org/data-and-statistics/data-product/emissions-factors-2022

14 The categories with the clearest overlap were as follows. Scope 1: Fuels (kWh Gross CV), [Biofuels excluded for the time], Passenger vehicles (miles) [excluding ev vehicles], Delivery Vehicles (miles). Scope 2: Electricity Generated (kWh), Steam and Heat (kWh). [Excluded electricity generated for EVs). Scope 3: Business Travel Air (km per passenger), Business Travel Land – Public (km per passenger), Business Travel Land – Private (miles) [excluding EV vehicles], Freighting goods (tonnes km).

15 Detailed activity data was sourced from Omnevue (an environmental, social and governance (ESG) accounting and reporting platform).

16 We make four further technical assumptions in performing the exercise. First, emission values of cloud computing were kept fixed since the necessary activity data inputs were not available. These values were estimated and reported directly by the companies. Second, the factors for purchased materials were not available in the US-EPA database. Therefore, the UK-Defra conversion factors were used as the comparable ones from US-EPA. Third, the emission factor for recycling refrigerators was not available in the US-EPA. Thus, to estimate the missing factor, we take the average of the factors for recycling metals, plastics and glass, which are the recyclable materials found in refrigerators. Fourth, the spend-based method was not applicable for certain categories of Scope 3. Therefore, we use the reported emission values for these categories when calculating the company-level spend-based results.

17 SMEs' GHG emissions account for 35% of the UK's total GHG emissions (British Business Bank, 2021). The estimated total GHG emissions in UK are 417.1 million CO2e (DESNZ, 2023).

18 For each scope of emissions, we start by estimating the differences in estimated emissions based on factors from UK-Defra and US-EPA. To estimate changes in return on equity due to the differences, we multiply the resulting differences with the coefficient provided by Bolton and Kacperczyk (2021). Then, we use the weighted average changes in return to represent the changes in company-level return. To estimate the market-level impact, we take the average of the three companies' changes in return on equity.

19 This calculation is based on a simple two-stage dividend discount model, whereby the cost of equity is assumed to rise by 46 basis points for 5 years. The other parameters of the model are an assumed growth rate of dividends of 5% per annum and an initial cost of equity of 9%.

20 Benmelech and Dlugosz (2010) find evidence consistent with such behaviour: mortgage-backed securities tranches rated solely by one agency were more likely to be downgraded in 2008 and suffered more severe downgrades.

21 International Auditing and Assurance Standards Board's (IAASB) International Standard on Assurance Engagements 3000 (ISAE 3000) and/or its US equivalent the Statements on Standards for Attestation Engagements (SSAEs). AT-C sections 105, Concepts Common to All Attestation Engagements, and 205, Examination Engagements, of Statements on Standards for Attestation Engagements (SSAEs). The SSAEs are commonly referred to as the attestation standards (AICPA, 2017). https://us.aicpa.org/content/dam/aicpa/interestareas/frc/auditattest/downloadabledocuments/attest-clarity/differences-between-isae-3000-at-c-105-and-205.pdf

22 Under ISAE 3000 practitioners can express a limited or reasonable opinion that the risk of material misstatement is low. In a limited assurance engagement, the practitioner collects less evidence and performs fewer tests than for a reasonable assurance engagement. The practitioner's opinion is expressed as a negative opinion for limited assurance and as a positive opinion for reasonable assurance. Such assurance of GHG emissions could both test and mitigate the effect of emission gaming.

23 'A distinguishing mark of the accountancy profession is its acceptance of the responsibility to act in the public interest (ICAEW, 2017).'

24 This is consistent with the approach taken in financial reporting standards. For example, US Accounting Standards Codification 740 states, 'If it is reasonably possible that the estimates used could change materially within the next 12 months, the reporting entity should disclose the nature of the uncertainty and include an indication that it is at least reasonably possible that a change in the estimate will occur in the near term as prescribed'.

25 Researchers at the global carbon project https://www.globalcarbonproject.org/ and the UNFCCC https://di.unfccc.int/ are working on this.

26 The limitation that smaller and medium sized businesses (SMEs), who do not currently have an obligation to report GHG emissions may not be included, is recognised. However, the Financial Conduct Authority (FCA) have expressed an ambition that SMEs will need to 'integrate the TCFD framework into their business model by 2025'. The EU is extending its CSRD reporting to publicly listed SMEs in 2026.

27 To support carbon pricing, strong industrial regulations must be enforced for embodied carbon certification within steel products, and a standard global emissions accounting method agreed upon that covers the entire product lifecycle. Lifecycle analysis methodologies and inventories must be consistent across the global market, especially regarding boundary definition and input data for emissions accounting tools. Alongside transparent embodied carbon declarations, publicly-available supply chain information should be mandated and normalised in annual company reports. https://www.cisl.cam.ac.uk/files/cisl_steel_sector_deep_dive_may_2023.pdf

28 https://unfccc.int/process-and-meetings/transparency-and-reporting/reporting-and-review-under-the-convention/greenhouse-gas-inventories-annex-i-parties/national-inventory-submissions-2023

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